US010818484B2

(12) **United States Patent**
Nagata et al.

(10) **Patent No.: US 10,818,484 B2**
(45) **Date of Patent: *Oct. 27, 2020**

(54) **MICROCHANNEL PLATE AND ELECTRON MULTIPLIER TUBE WITH IMPROVED GAIN AND SUPPRESSED DETERIORATION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **16/489,004**

(22) PCT Filed: **Jan. 23, 2018**

(86) PCT No.: **PCT/JP2018/001984**

§ 371 (c)(1),
(2) Date: **Aug. 27, 2019**

(87) PCT Pub. No.: **WO2018/159159**

PCT Pub. Date: **Sep. 7, 2018**

(65) **Prior Publication Data**

US 2020/0027709 A1 Jan. 23, 2020

(30) **Foreign Application Priority Data**

Mar. 1, 2017 (JP) 2017-038463

(51) **Int. Cl.**
H01J 43/24 (2006.01)

(52) **U.S. Cl.**
CPC ***H01J 43/246*** (2013.01); *H01J 43/243* (2013.01); *H01J 2237/24435* (2013.01)

(58) **Field of Classification Search**
CPC H01J 43/246; H01J 43/243; H01J 2237/24435
See application file for complete search history.

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Primary Examiner — Tracie Y Green
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(57) **ABSTRACT**

A microchannel plate is provided with a substrate including a front surface, a rear surface, and a side surface, a plurality of channels penetrating from the front surface to the rear surface of the substrate, a first film provided on at least an inner wall surface of the channel, a second film provided on at least a part of the first film, and electrode layers provided on the front surface and the rear surface of the substrate. The first film is made of MgO, the second film is made of SiO_2, and the second film is thinner than the first film.

26 Claims, 17 Drawing Sheets

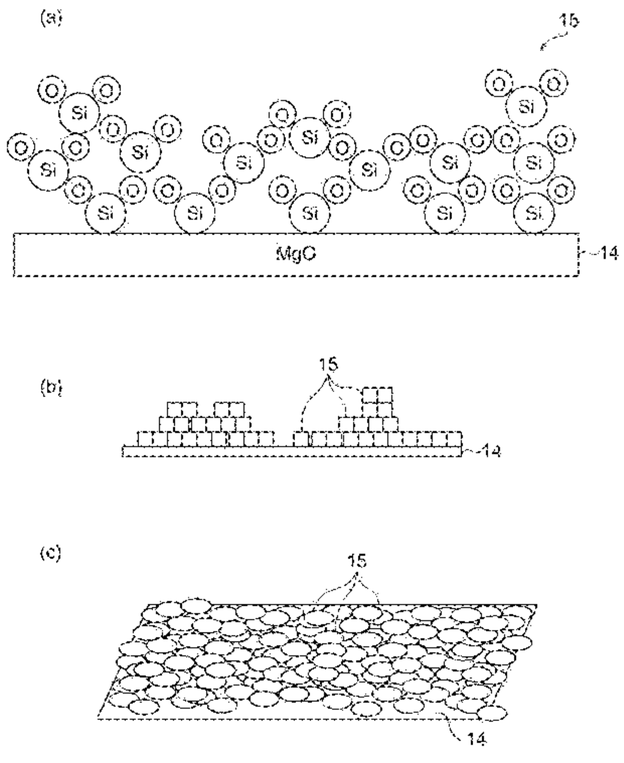

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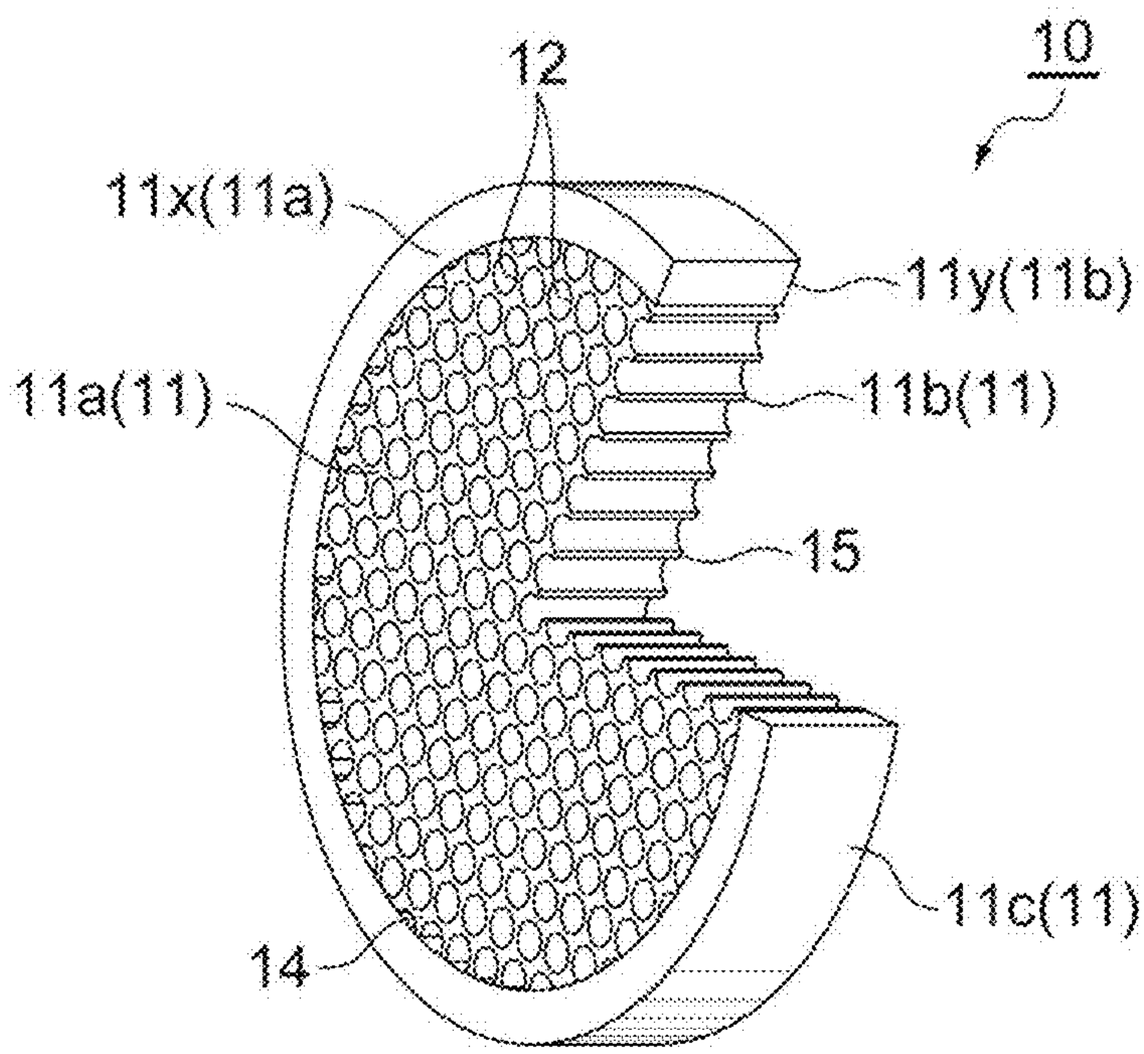
Fig.1

(a)


12
10
11x(11a)
11y(11b)
11a(11)
11b(11)
15
11c(11)
14

(b)

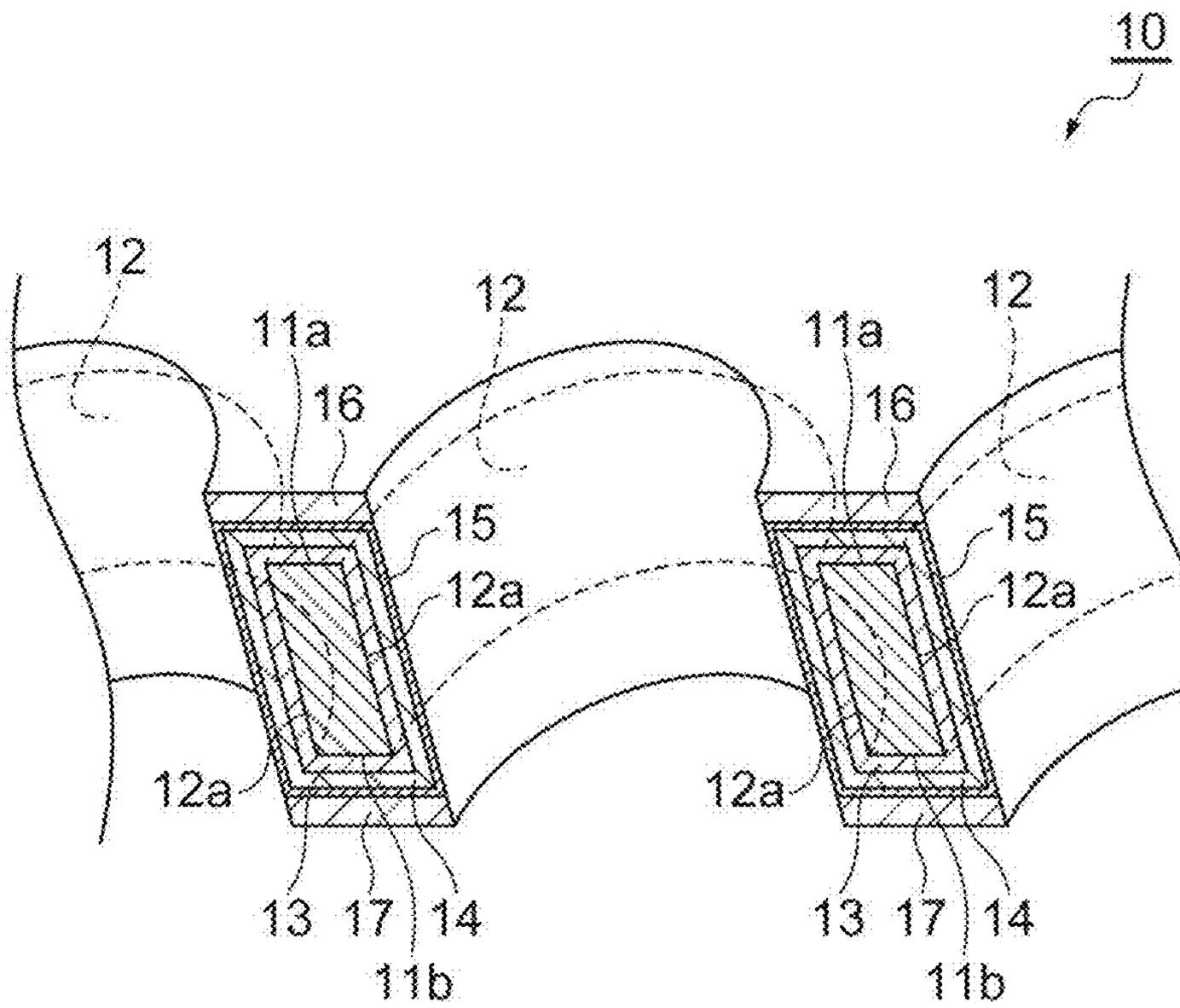

10
12
11a
16
15
12a
13
17
14
11b

Fig.2

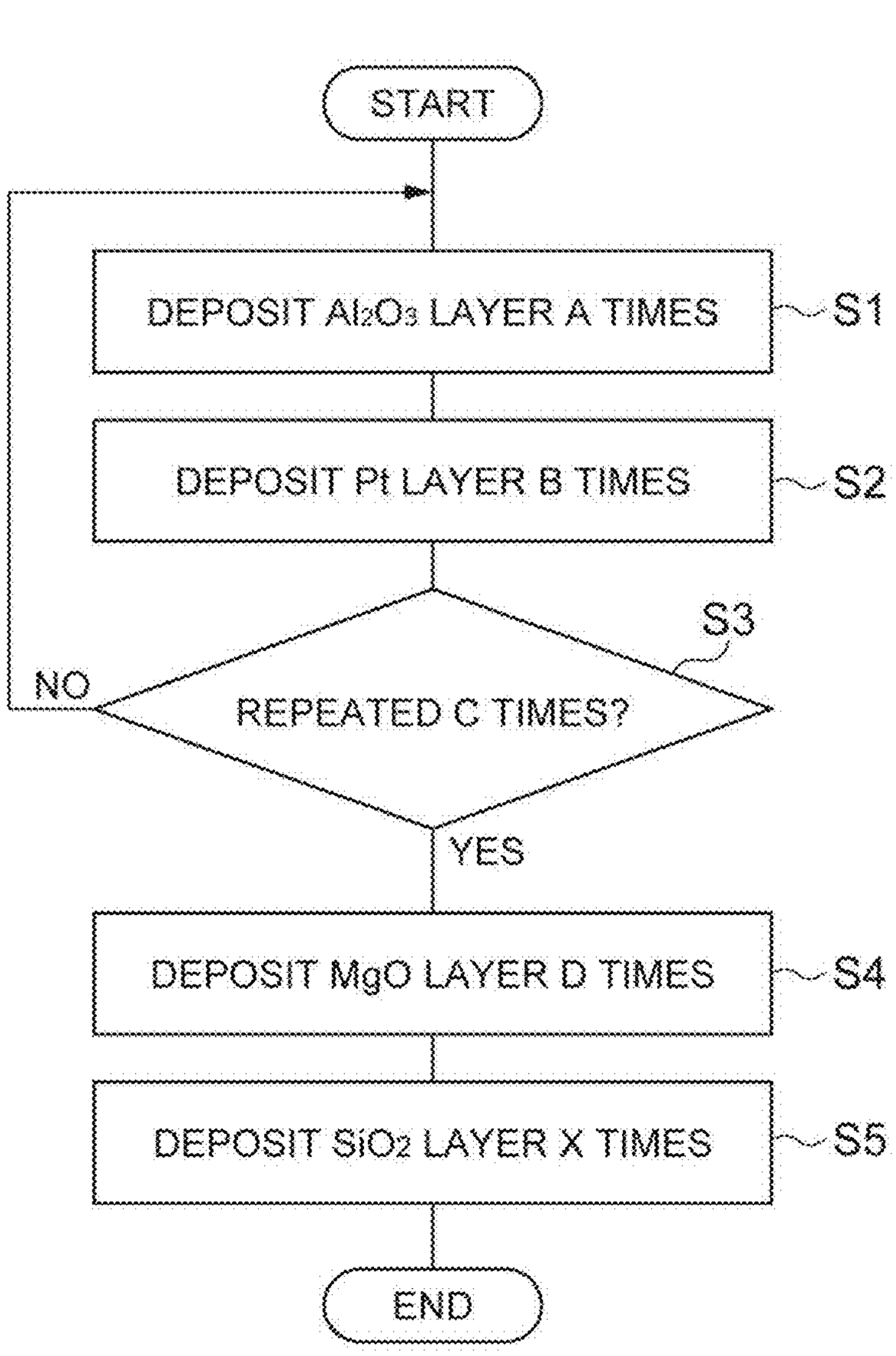

START
DEPOSIT Al_2O_3 LAYER A TIMES
S1
DEPOSIT Pt LAYER B TIMES
S2
S3
NO
REPEATED C TIMES?
YES
DEPOSIT MgO LAYER D TIMES
S4
DEPOSIT SiO_2 LAYER X TIMES
S5
END

Fig.3

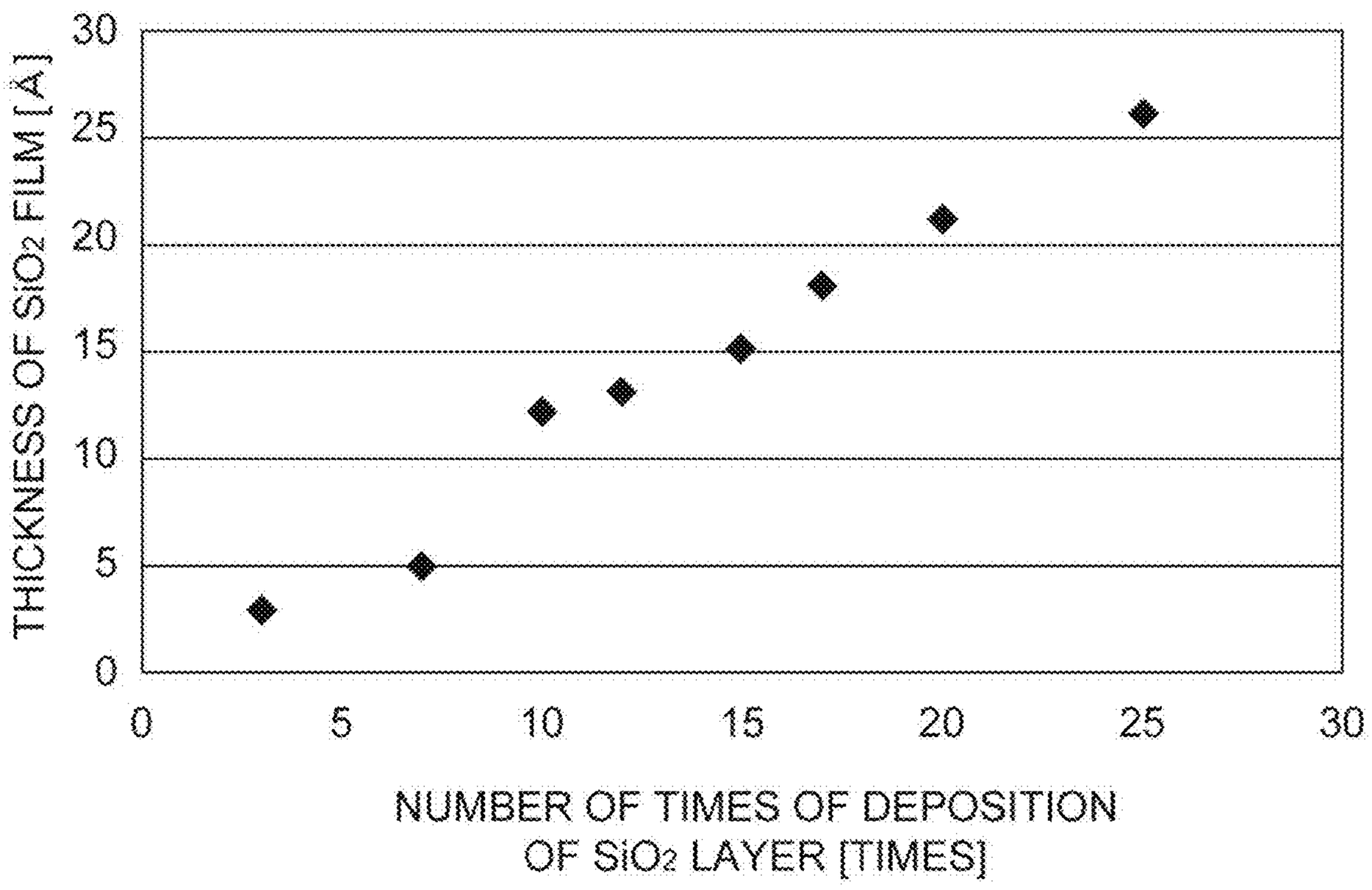

THICKNESS OF SiO_2 FILM [Å]
0
5
10
15
20
25
30
0
5
10
15
20
25
30
NUMBER OF TIMES OF DEPOSITION OF SiO_2 LAYER [TIMES]

Fig.4

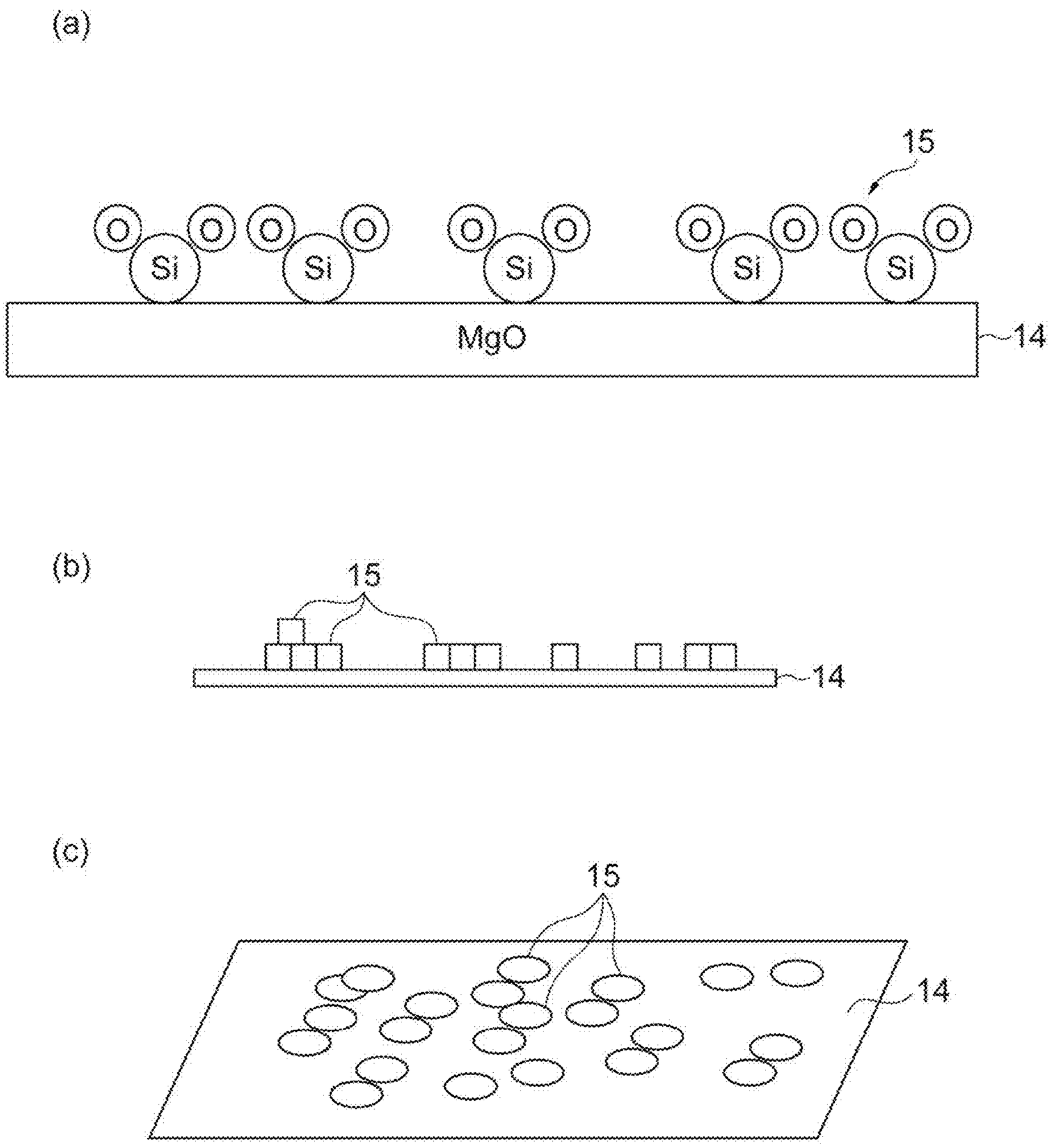


Fig.5

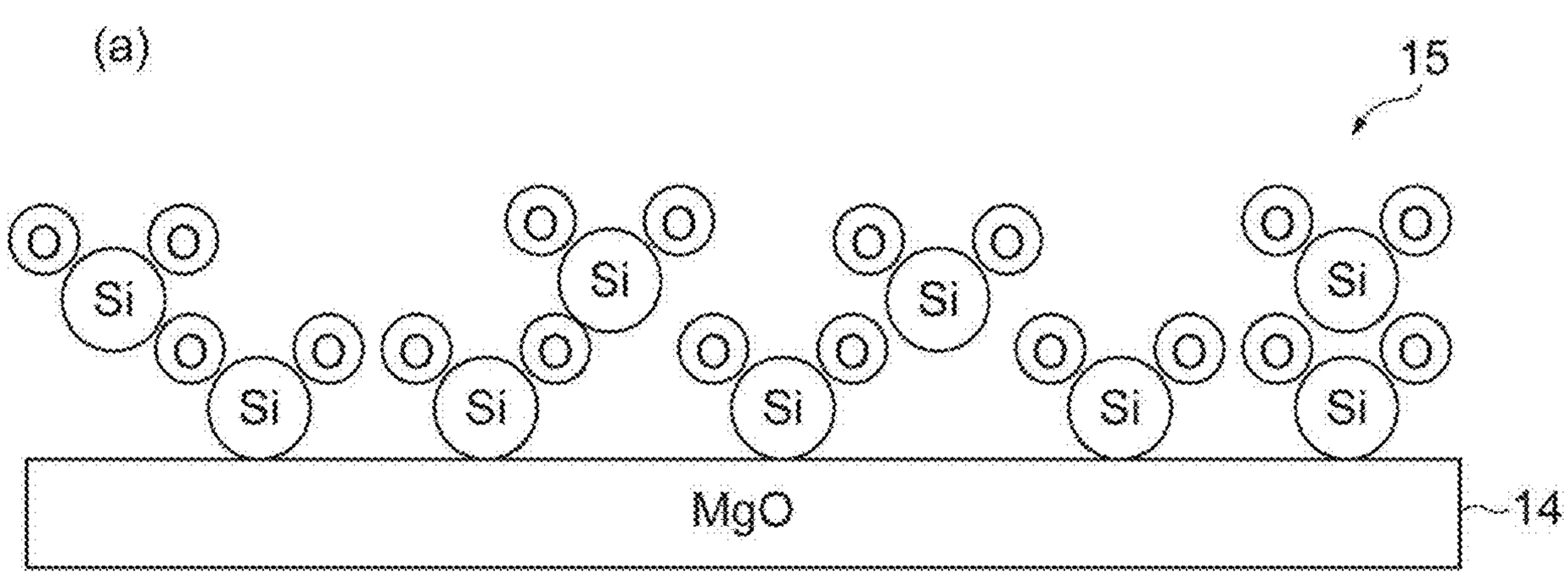
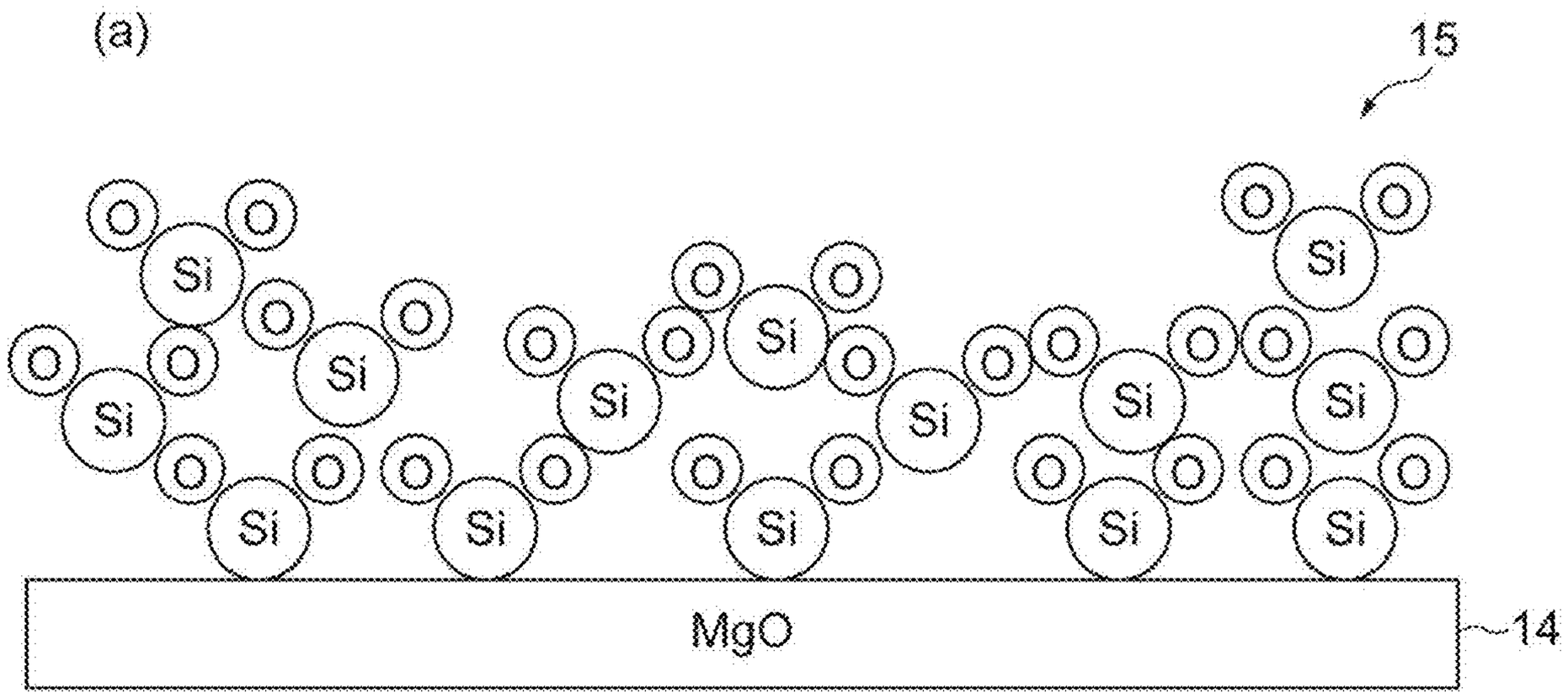
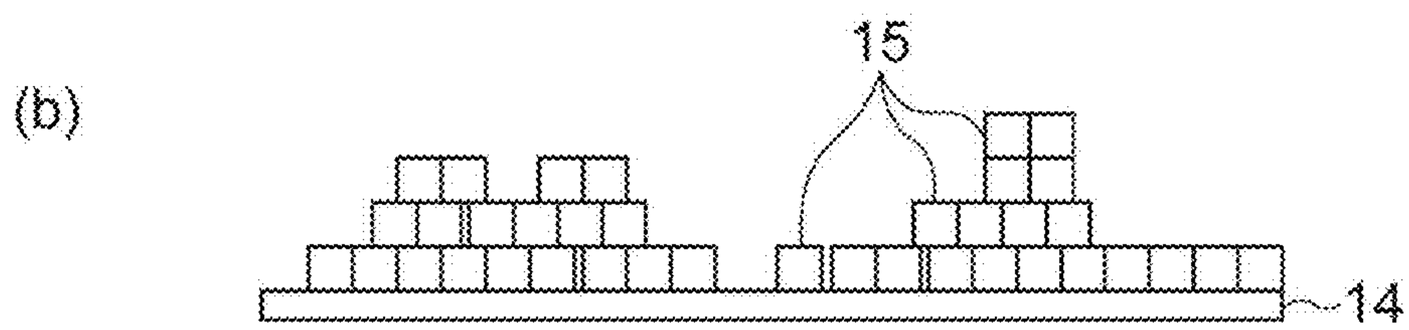


Fig.6





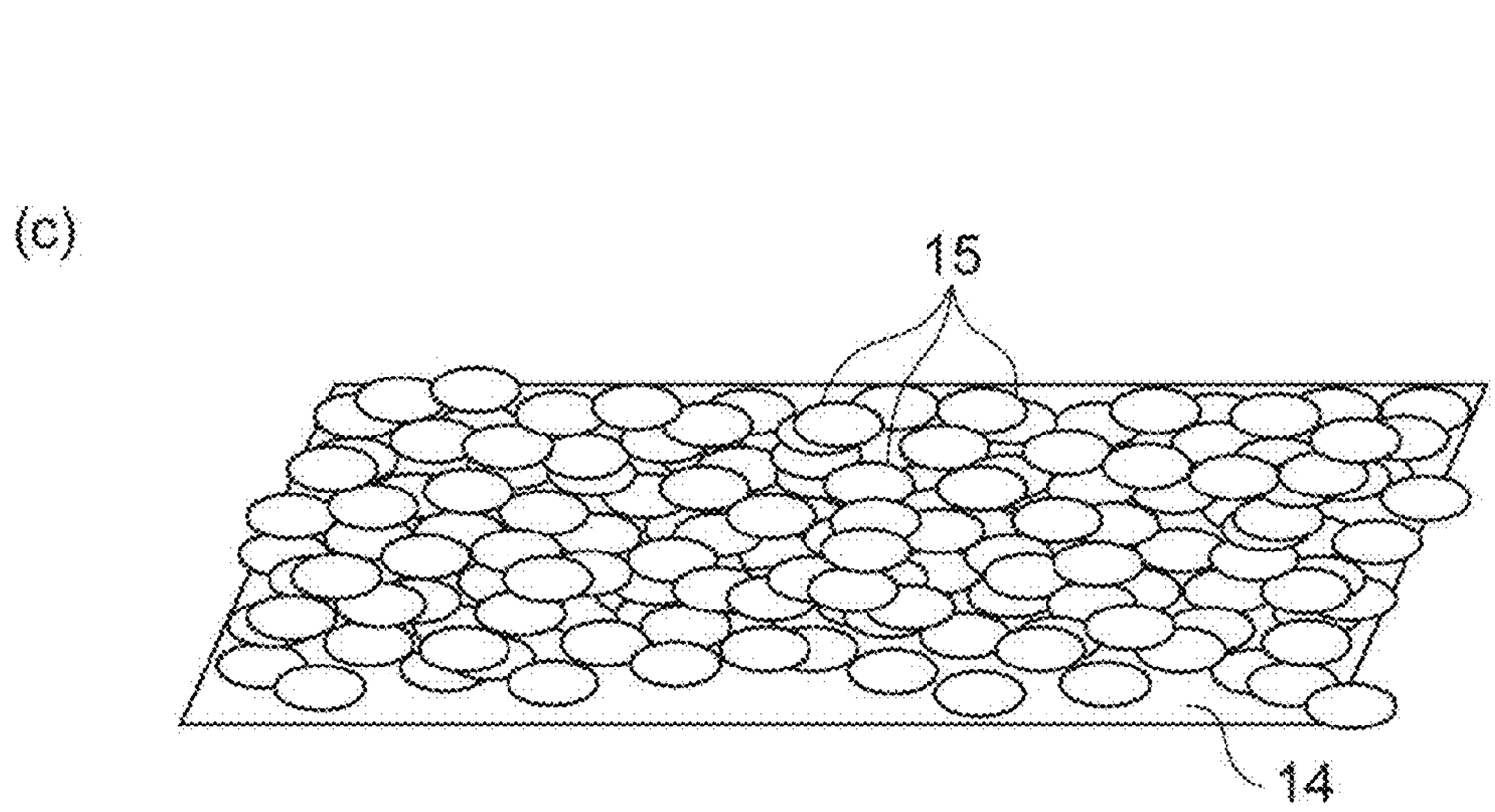
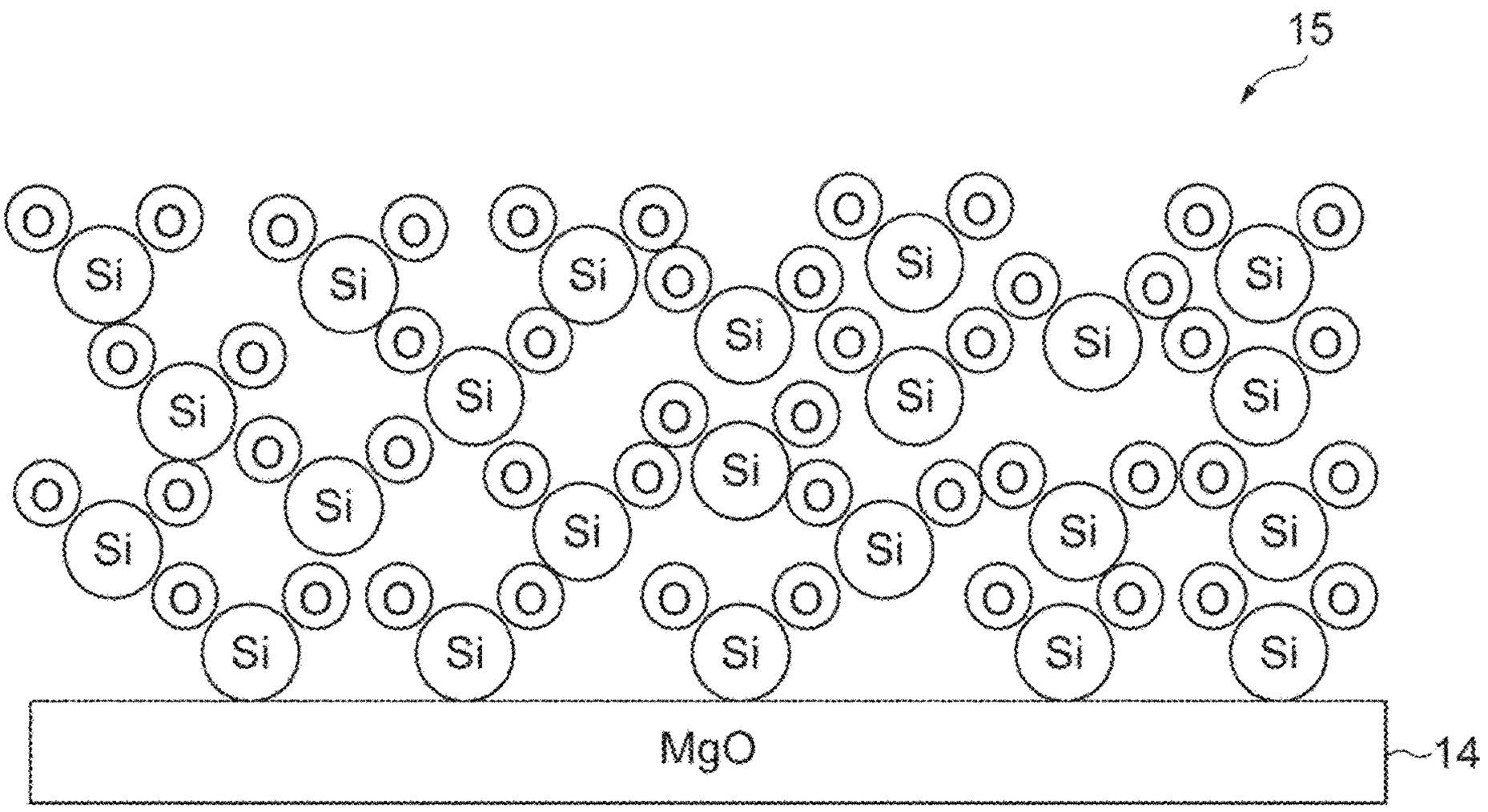


Fig.7



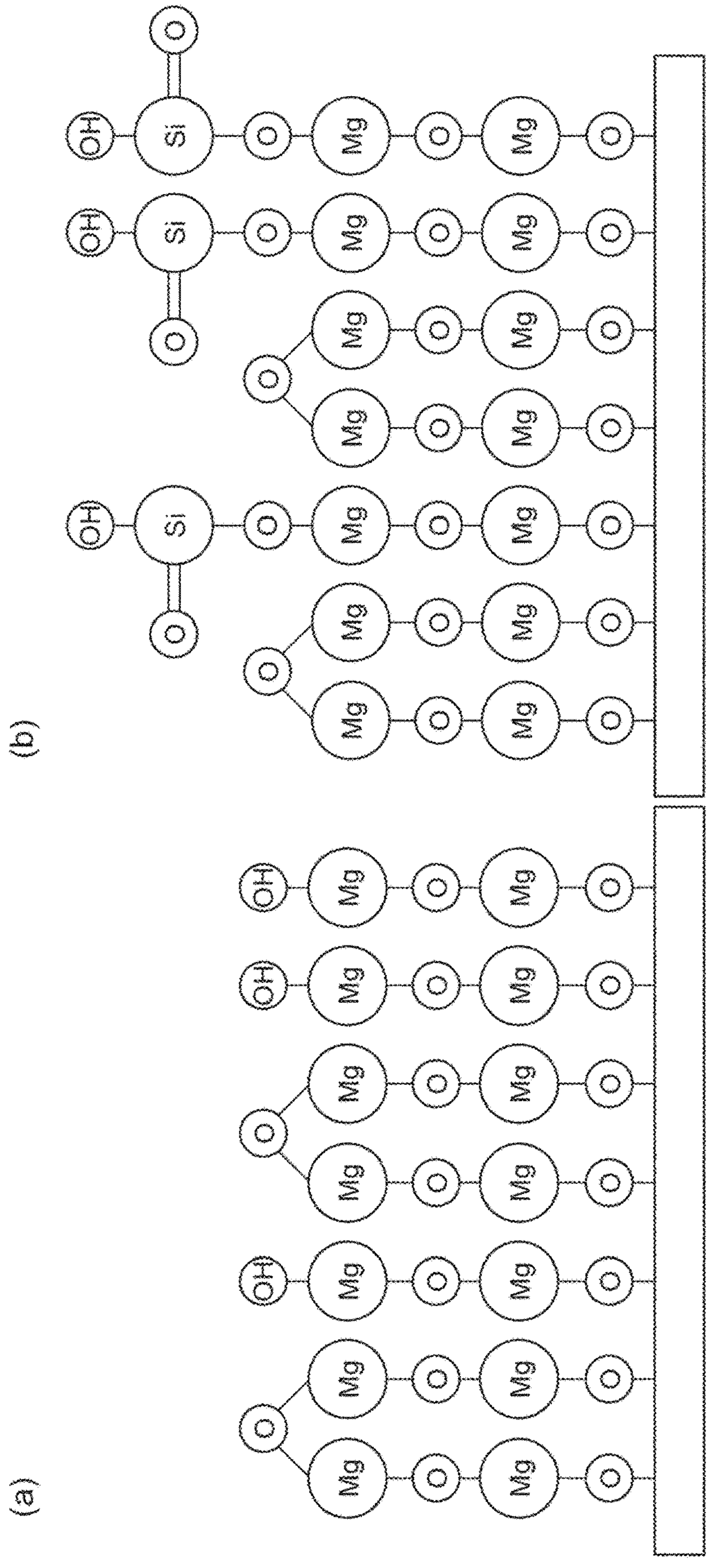


Fig.8

Fig.9

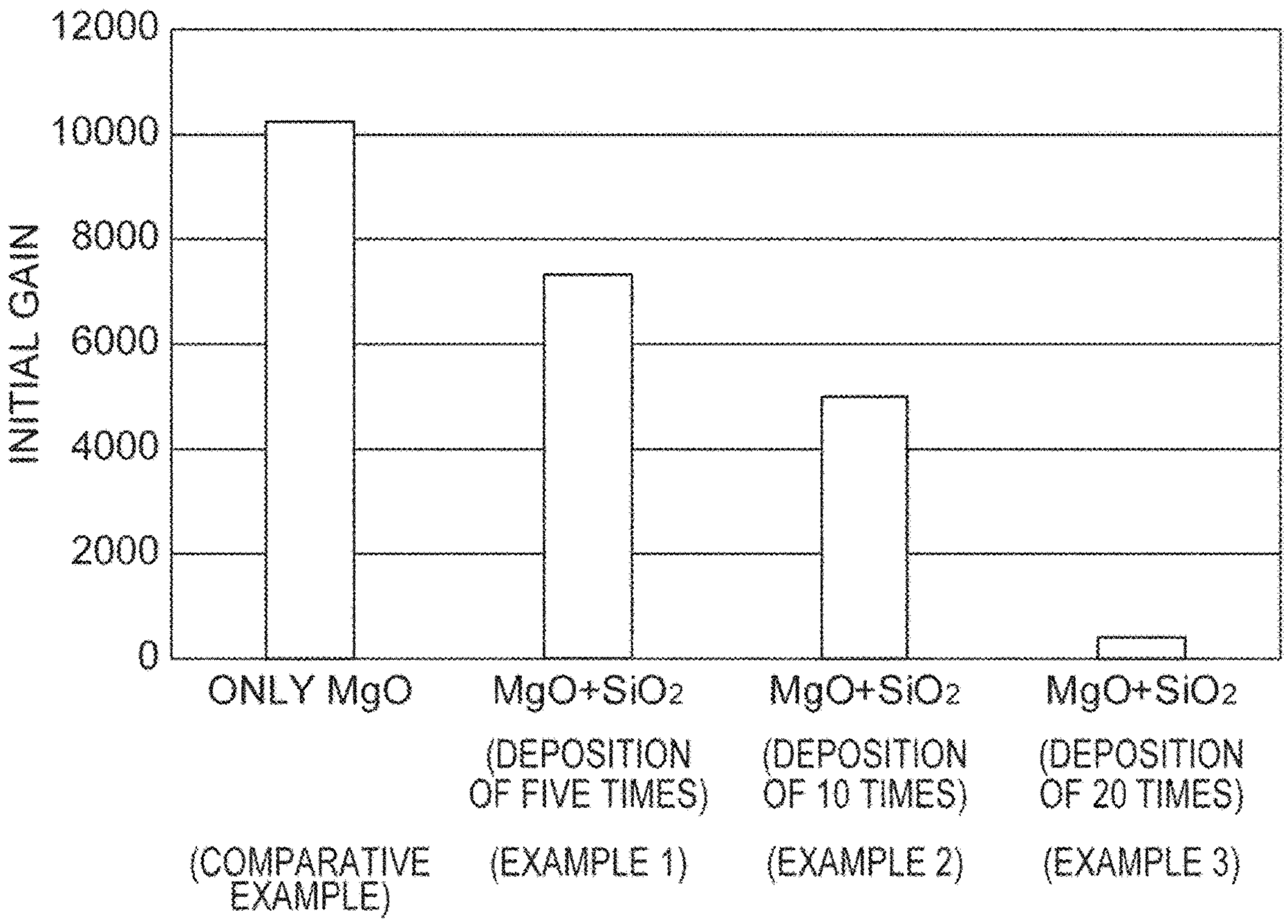

12000
10000
8000
6000
4000
2000
0
INITIAL GAIN
ONLY MgO
(COMPARATIVE EXAMPLE)
MgO+SiO2
(DEPOSITION OF FIVE TIMES)
(EXAMPLE 1)
MgO+SiO2
(DEPOSITION OF 10 TIMES)
(EXAMPLE 2)
MgO+SiO2
(DEPOSITION OF 20 TIMES)
(EXAMPLE 3)

Fig.10

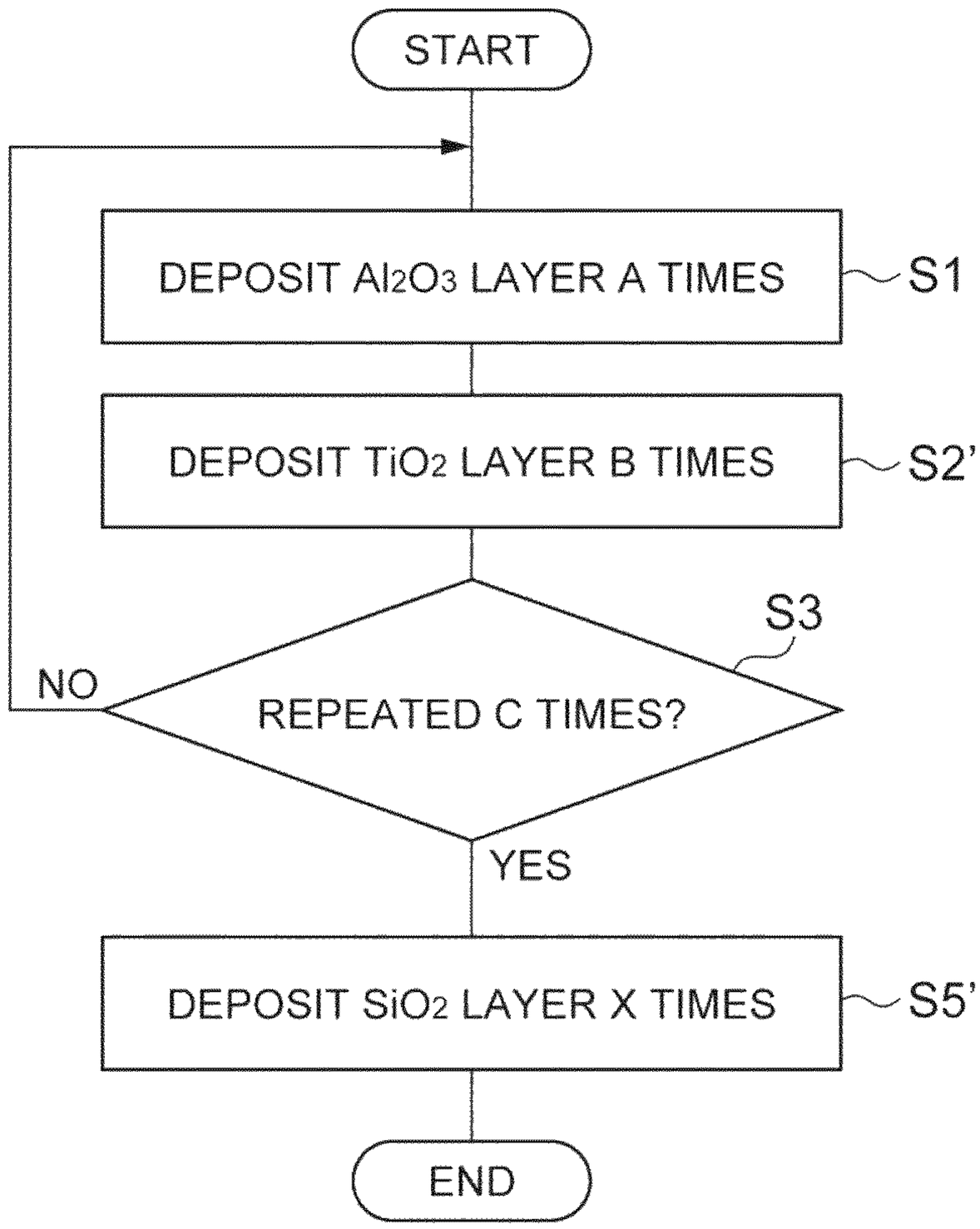

START
DEPOSIT Al_2O_3 LAYER A TIMES
S1
DEPOSIT TiO_2 LAYER B TIMES
S2'
S3
NO
REPEATED C TIMES?
YES
DEPOSIT SiO_2 LAYER X TIMES
S5'
END

Fig.11

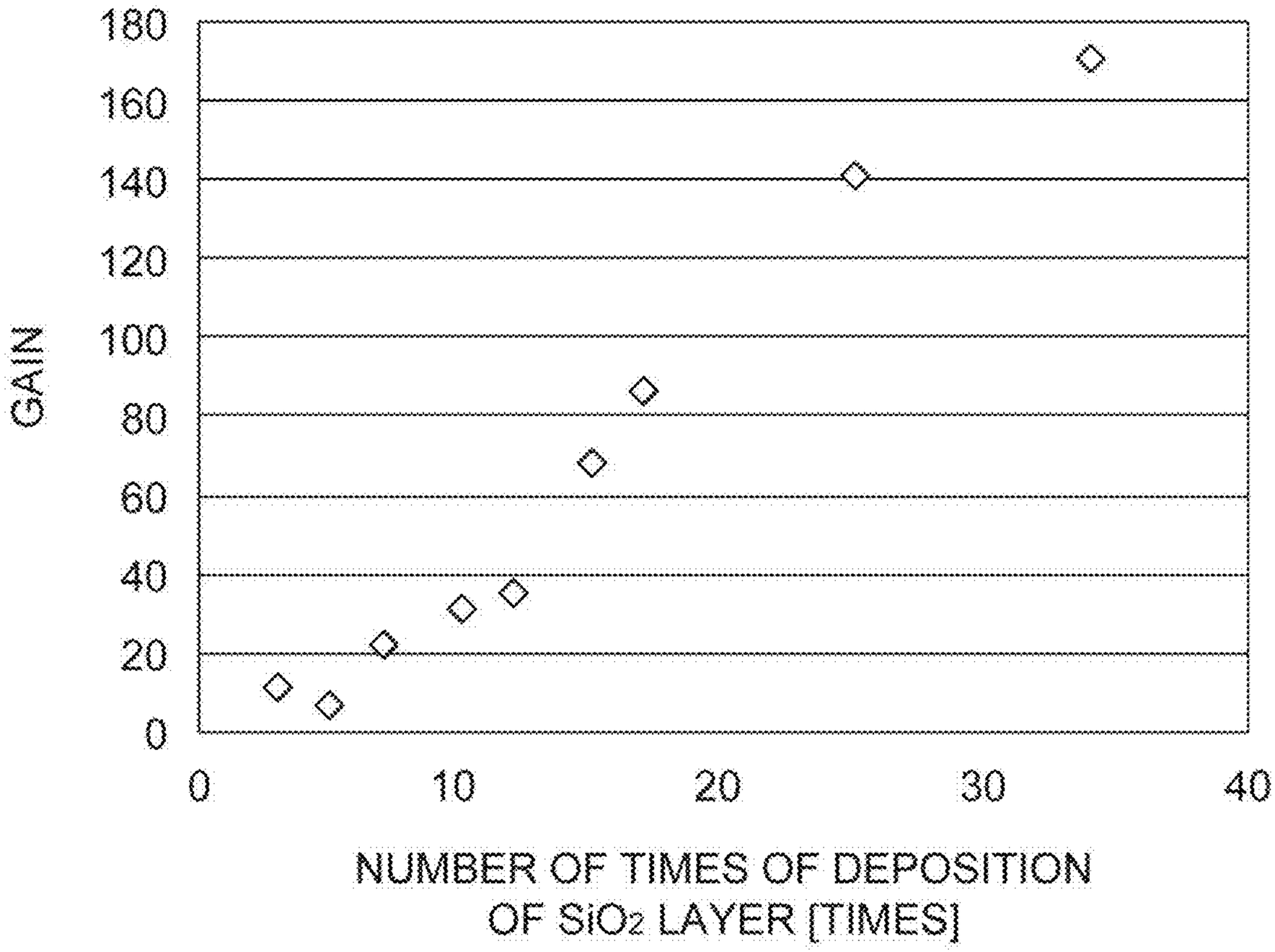

180
160
140
120
100
80
60
40
20
0
GAIN
0
10
20
30
40
NUMBER OF TIMES OF DEPOSITION
OF SiO2 LAYER [TIMES]

Fig.12

(atm%)

	C	O	F	Mg	Si	Fe	$MgO:MgCO_3$
ONLY MgO (COMPARATIVE EXAMPLE)	45.8	35.7	1.3	17.2			57:43
$MgO+SiO_2$ (DEPOSITION OF FIVE TIMES) (EXAMPLE 1)	34.2	36.2	2.7	25	1.9		86:14
$MgO+SiO_2$ (DEPOSITION OF 10 TIMES) (EXAMPLE 2)	22.7	45.3	2.4	22.1	6.5	1.1	87:13

Fig.13

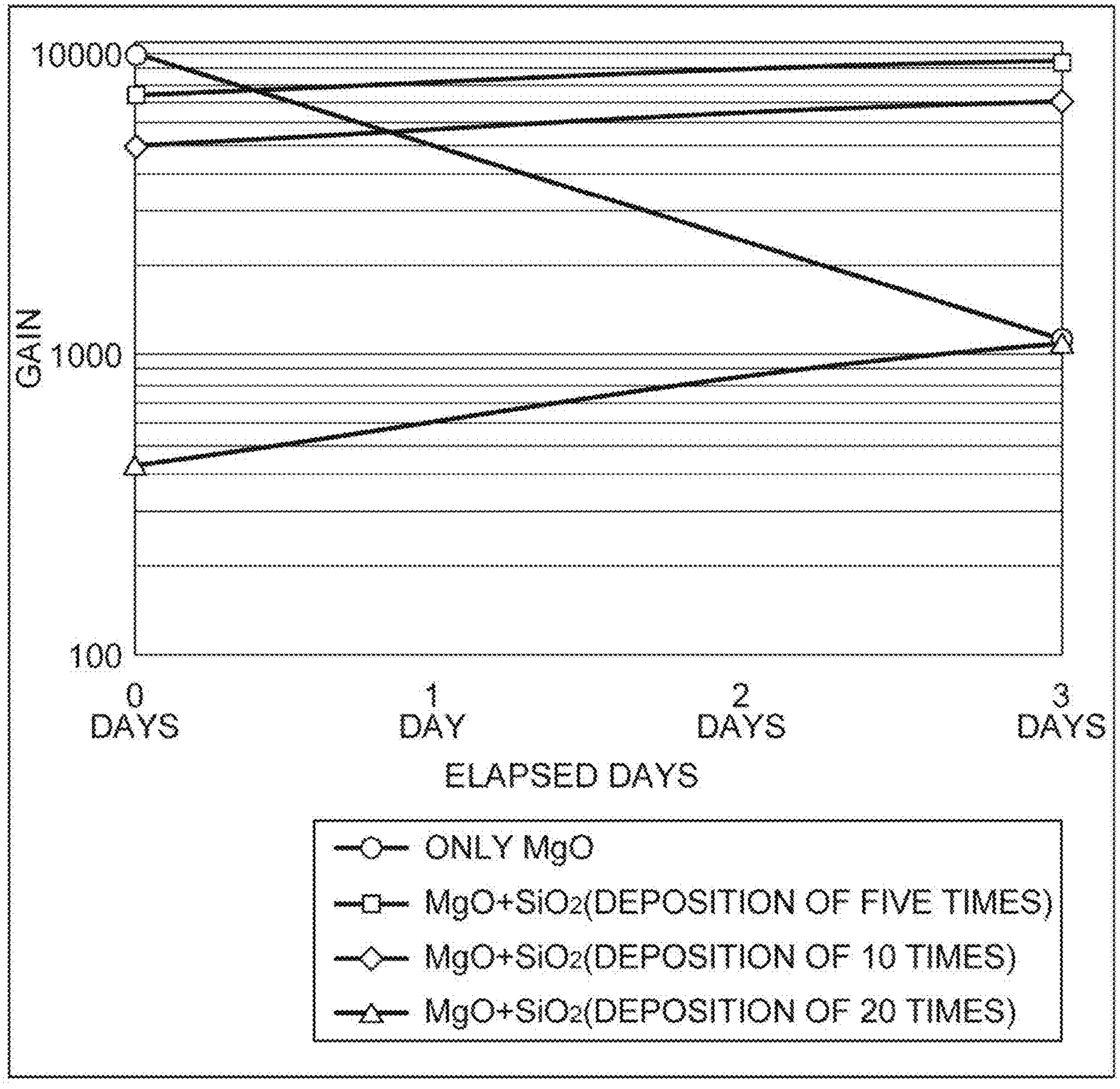

10000
1000
100
GAIN
0 DAYS
1 DAY
2 DAYS
3 DAYS
ELAPSED DAYS
ONLY MgO
MgO+SiO2(DEPOSITION OF FIVE TIMES)
MgO+SiO2(DEPOSITION OF 10 TIMES)
MgO+SiO2(DEPOSITION OF 20 TIMES)

Fig.14

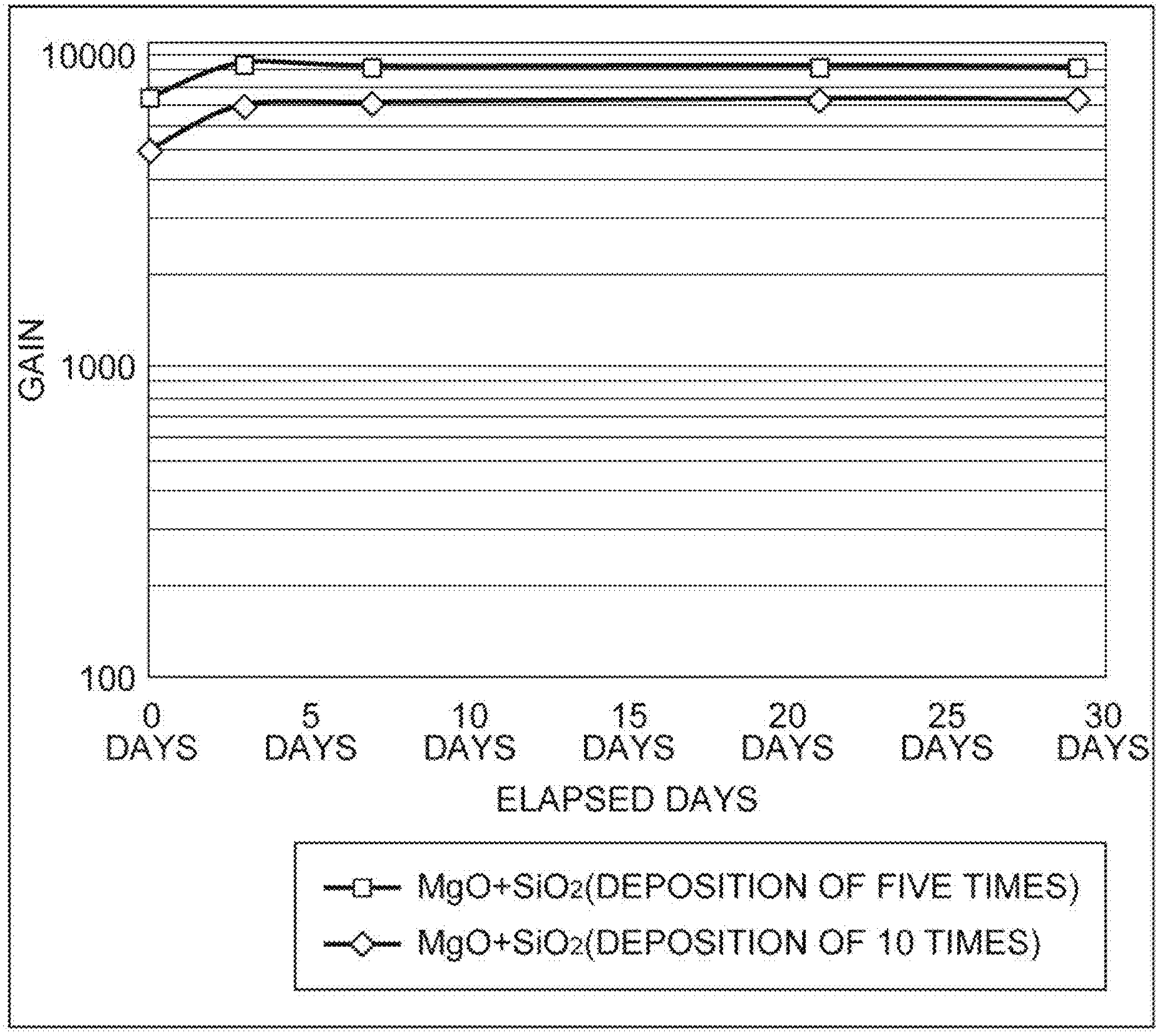

10000
1000
100
GAIN
0 DAYS
5 DAYS
10 DAYS
15 DAYS
20 DAYS
25 DAYS
30 DAYS
ELAPSED DAYS
MgO+SiO2(DEPOSITION OF FIVE TIMES)
MgO+SiO2(DEPOSITION OF 10 TIMES)

Fig.15

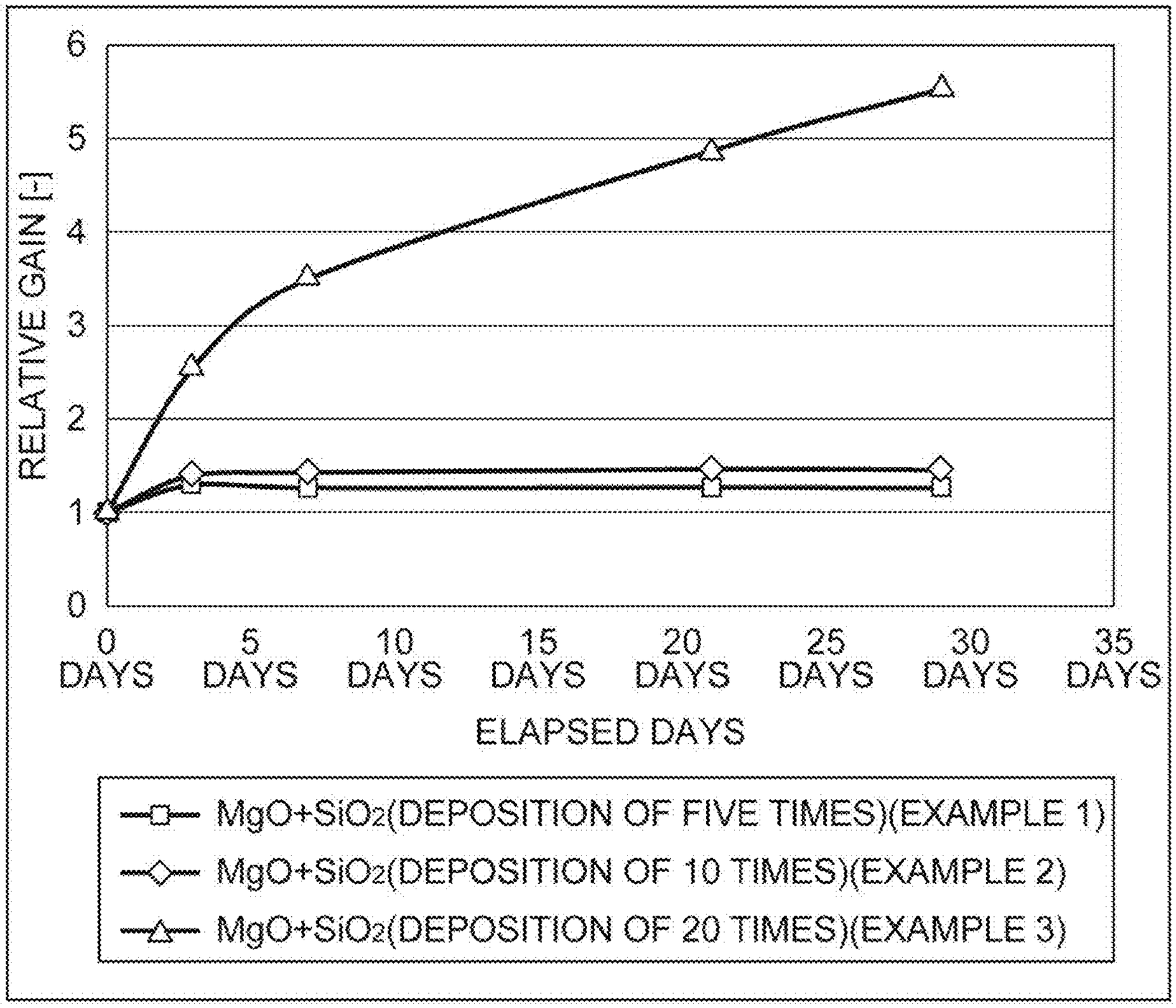

RELATIVE GAIN [-]
0
1
2
3
4
5
6
0 DAYS
5 DAYS
10 DAYS
15 DAYS
20 DAYS
25 DAYS
30 DAYS
35 DAYS
ELAPSED DAYS
MgO+SiO2(DEPOSITION OF FIVE TIMES)(EXAMPLE 1)
MgO+SiO2(DEPOSITION OF 10 TIMES)(EXAMPLE 2)
MgO+SiO2(DEPOSITION OF 20 TIMES)(EXAMPLE 3)

Fig.16

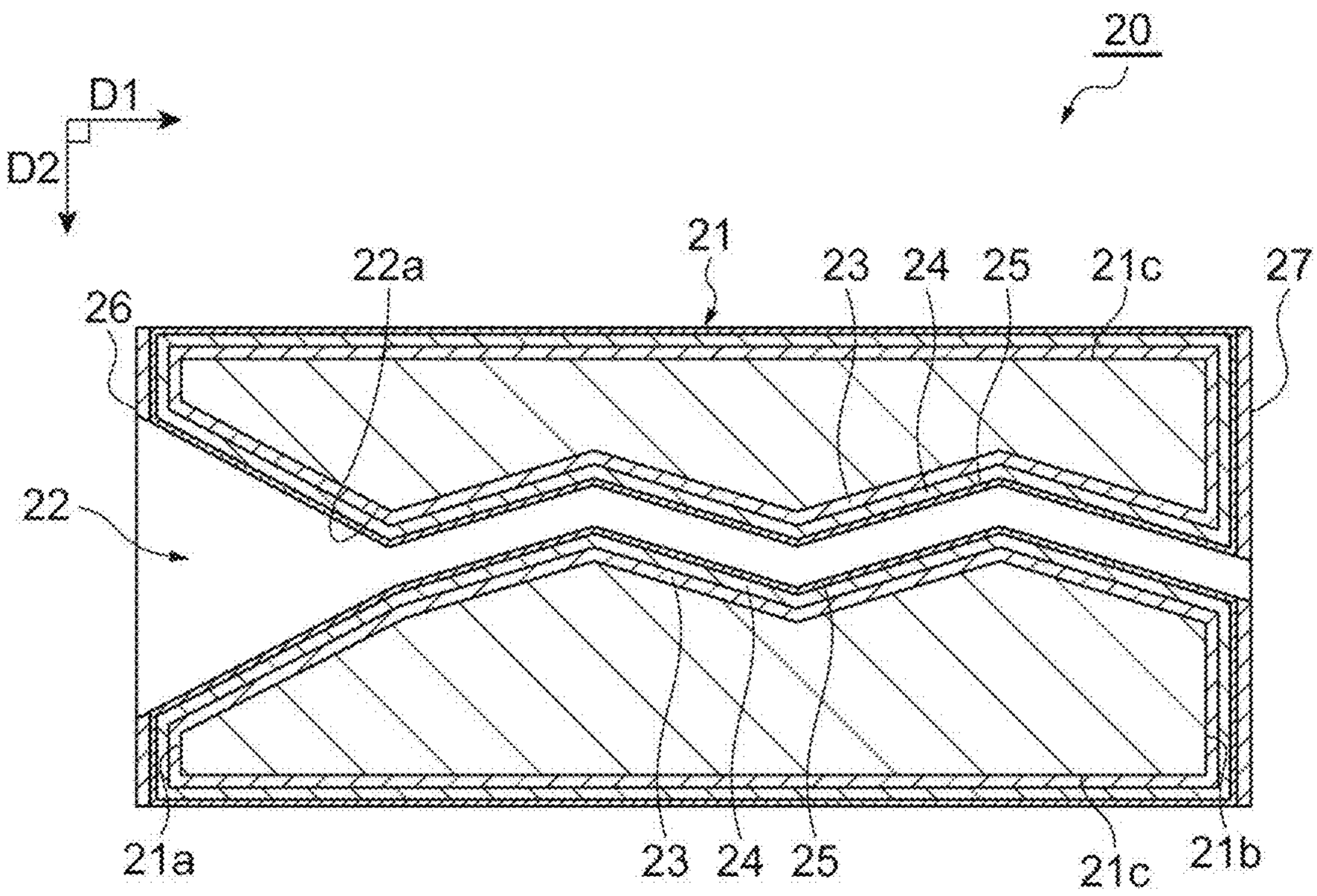
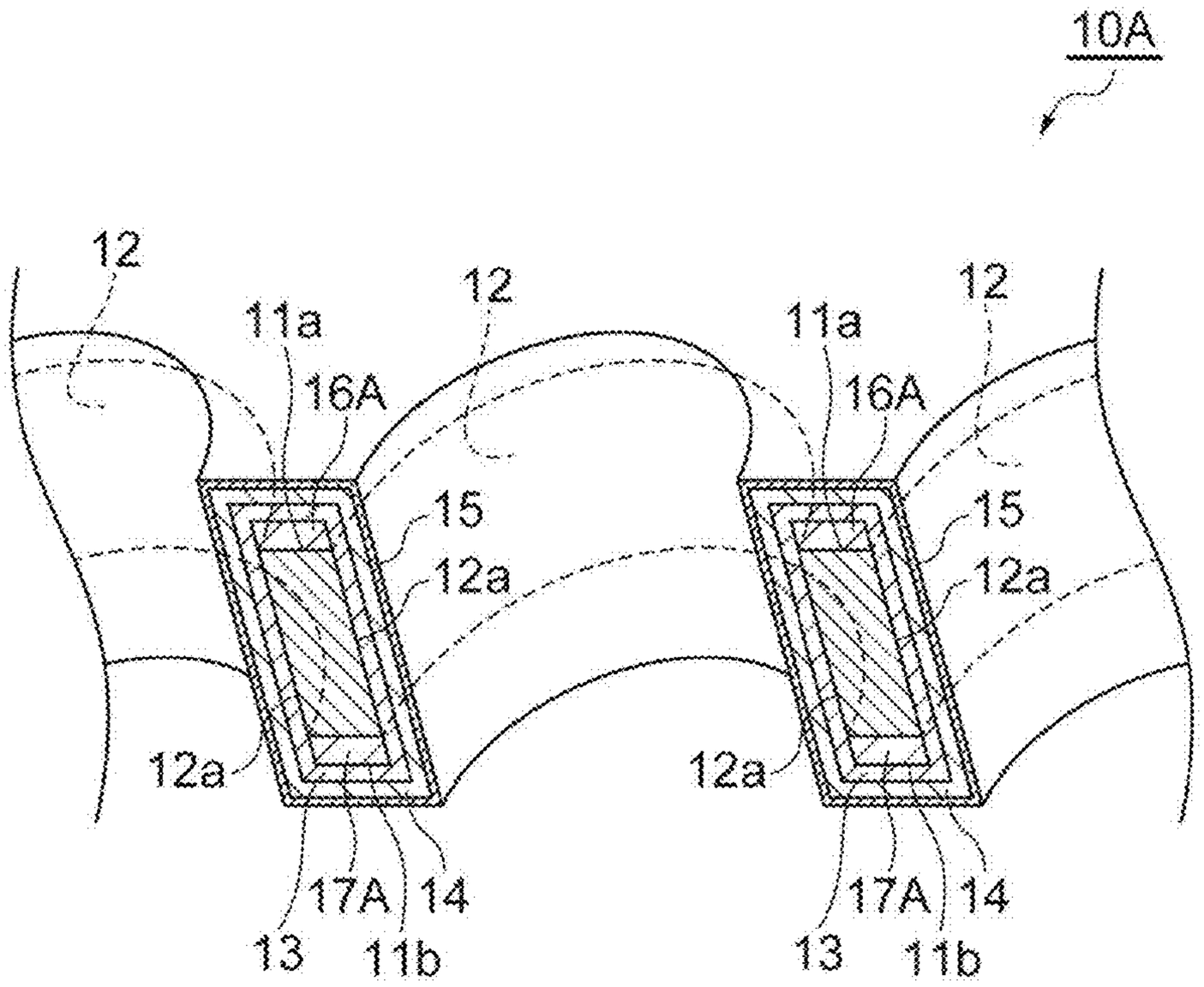
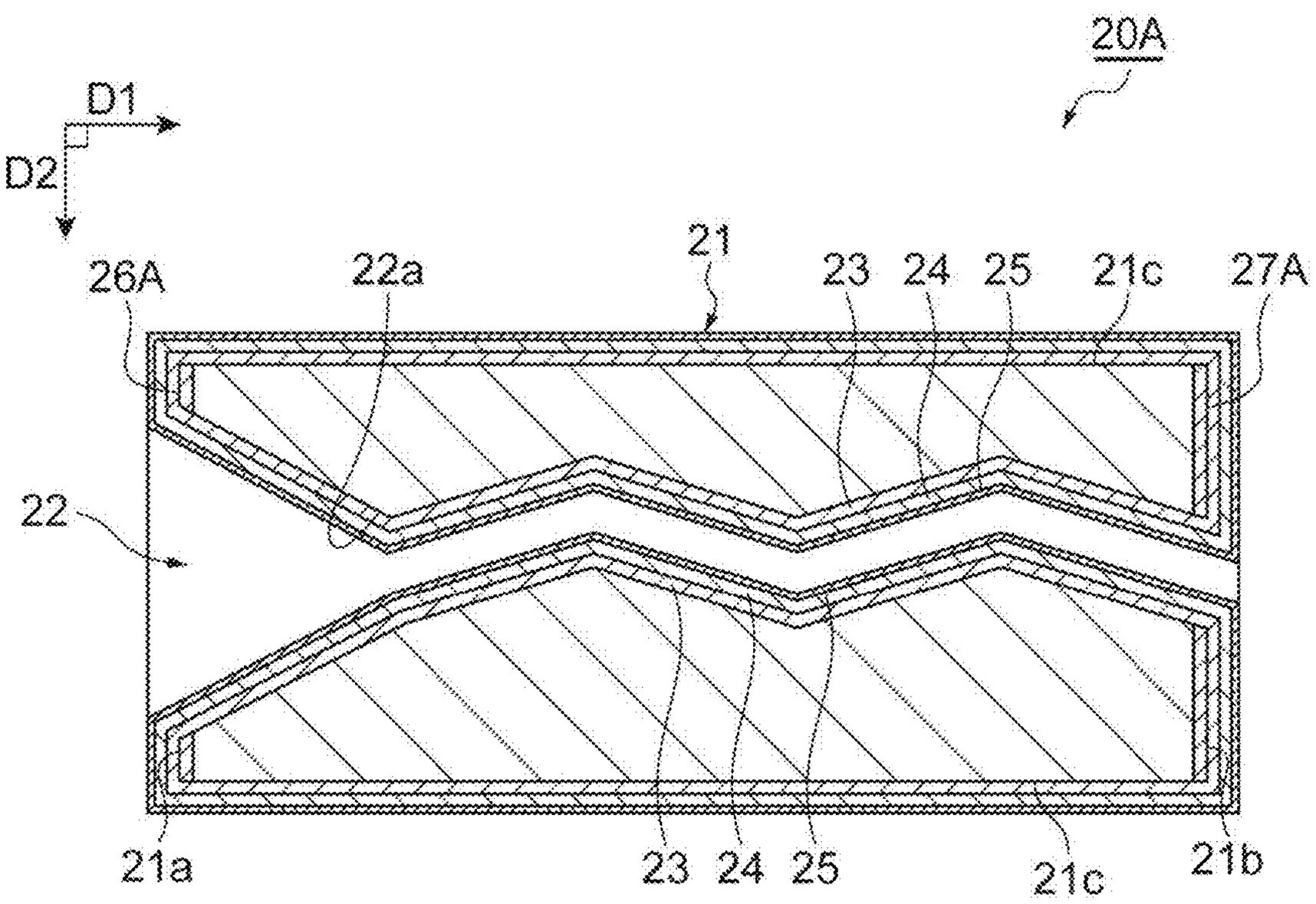


Fig.17

(a)


10A
12
11a
16A
12
12
11a
16A
12
15
12a
15
12a
12a
12a
17A
14
17A
14
13
11b
13
11b

(b)


20A
D1
D2
26A
22a
21
23
24
25
21c
27A
22
21a
23
24
25
21c
21b

MICROCHANNEL PLATE AND ELECTRON MULTIPLIER TUBE WITH IMPROVED GAIN AND SUPPRESSED DETERIORATION

TECHNICAL FIELD

One aspect of the present invention relates to a microchannel plate and an electron multiplier.

BACKGROUND ART

Conventionally, a microchannel plate provided with a substrate including a front surface and a rear surface and a plurality of channels penetrating from the front surface to the rear surface of the substrate is known (refer to, for example, Patent Document 1). In this microchannel plate, a first emission layer is formed in the channel and a second emission layer is formed on the first emission layer.

CITATION LIST

Patent Literature

Patent Document 1: Japanese Unexamined Patent Application Publication No. 2011-513921

SUMMARY OF INVENTION

Technical Problem

Generally, a microchannel plate is a device used in a vacuum tube such as an image intensifier or a photomultiplier tube. When handleability during manufacture and a transport environment to customers of the microchannel plate alone are taken into consideration, stability of a characteristic under an environment different from the environment of the vacuum tube is important for the microchannel plate. In the conventional technology described above, for example, in a case where the microchannel plate is exposed to the atmosphere, a surface of the second emission layer formed of an Al_2O_3 layer is contaminated or altered, and as a result, gain might be deteriorated over time. In the above-described conventional technology, since magnitude of secondary electron emission coefficients of the first emission layer and the second emission layer are not sufficiently taken into consideration in a configuration of the microchannel plate, for example, even if the secondary electron emission coefficient of the first emission layer is large, it is not possible to utilize a characteristic of the first emission layer and gain of the microchannel plate might be lowered.

An object of one aspect of the present invention is to provide a microchannel plate and an electron multiplier capable of improving the gain while suppressing deterioration in gain over time.

Solution to Problem

In order to solve the above-described problem, the inventors of the present invention exhaustively studied. As a result, the inventors of the present invention found that the deterioration in gain over time during the time of exposure to the atmosphere, for example, may be suppressed by providing a first film made of MgO (magnesium oxide) on an inner wall surface of a channel and providing a second film made of SiO_2 (silicon dioxide) on at least a part of the first film. In addition, the inventors of the present invention found that it is possible to utilize a characteristic of MgO having a large secondary electron emission coefficient to efficiently improve the gain by making the second film made of SiO_2 thinner than the first film made of MgO. Furthermore, the inventors found that the gain increases from initial gain immediately before exposure to the atmosphere after the exposure to the atmosphere when the first film is made of MgO and the second film is made of SiO_2, and achieved the present invention.

A microchannel plate according to one aspect of the present invention is provided with a substrate including a front surface, a rear surface, and a side surface, a plurality of channels penetrating from the front surface to the rear surface of the substrate, a first film provided on at least an inner wall surface of the channel, a second film provided on at least a part of the first film, and electrode layers provided on the front surface and the rear surface of the substrate, in which the first film is made of MgO, the second film is made of SiO_2, and the second film is thinner than the first film.

In the microchannel plate, since the second film made of SiO_2 is provided on at least a part of the first film made of MgO, it is possible to suppress deterioration in gain over time during the time of the exposure to the atmosphere, for example. In addition, since the second film made of SiO_2 is made thinner than the first film made of MgO, it is possible to allow the first film made of MgO to serve as a main secondary electron multiplier layer while utilizing a characteristic of MgO having a large secondary electron emission coefficient, thereby efficiently improving the gain. Furthermore, since the first film is made of MgO and the second film is made of SiO_2, the gain may be increased from the initial gain after the exposure to the atmosphere. Therefore, it is possible to improve the gain while suppressing the deterioration in gain over time.

In the microchannel plate according to one aspect of the present invention, the second film may be distributed in an island shape on the first film. In this case, it is possible to further improve the gain by allowing the first film to more effectively serve as the secondary electron multiplier layer while sufficiently securing the effect of suppressing the deterioration in gain over time.

In the microchannel plate according to one aspect of the present invention, a thickness of the first film may be 10 Å or more when being calculated using X-ray fluorescence analysis. If the first film made of MgO has the thickness of 10 Å or more in this manner, the first film may be allowed to effectively serve as the secondary electron multiplier layer.

In the microchannel plate according to one aspect of the present invention, the substrate may be made of an insulating material, and a resistance film may be formed between the inner wall surface of the channel and the first film. In this case, a potential gradient is formed by the resistance film when voltage is applied between the electrode layer provided on the front surface of the substrate and the electrode layer provided on the rear surface of the substrate, and electron multiplication becomes possible.

In the microchannel plate according to one aspect of the present invention, the substrate may be made of a resistant material. In this case, it is unnecessary to provide the resistance film on the inner wall surface of the channel, and a manufacturing process of the resistance film may be omitted, so that a manufacturing cost may be reduced.

In the microchannel plate according to one aspect of the present invention, the first film and the second film may be formed on the front surface, the rear surface, and the side surface of the substrate, and the electrode layers may be formed on the second film. Alternatively, the electrode

layers may be formed so as to be in contact with the front surface and the rear surface of the substrate, and the first film and the second film may be formed on the electrode layers, and the front surface, the rear surface, and the side surface of the substrate. In these configurations, gas emission from the substrate may be effectively suppressed in a case where the substrate is made of a material which emits a large amount of gas, for example, since the first film and the second film cover the front surface, the rear surface, and the side surface of the substrate.

In the microchannel plate according to one aspect of the present invention, the resistance film, the first film, and the second film may be formed on the front surface, the rear surface, and the side surface of the substrate, and the electrode layers may be formed on the second film. Alternatively, the electrode layers may be formed so as to be in contact with the front surface and the rear surface of the substrate, and the resistance film, the first film, and the second film may be formed on the front surface, the rear surface, and the side surface of the substrate. In these configurations, gas emission from the substrate may be effectively suppressed in a case where the substrate is made of a material which emits a large amount of gas, for example, since not only the first film and the second film but also the resistance film cover the front surface, the rear surface, and the side surface of the substrate.

In the microchannel plate according to one aspect of the present invention, the first film and the second film may be layers formed by atomic layer deposition. In this case, since the first film and the second film may be formed at an atomic layer level, a film in which a defect such as a pinhole is suppressed with a uniform film quality may be formed.

An electron multiplier according to one aspect of the present invention is provided with a main body including a front surface, a rear surface, and a side surface, a channel penetrating from the front surface to the rear surface of the main body, a first film provided on at least an inner wall surface of the channel, a second film provided on at least a part of the first film, and electrode layers provided on the front surface and the rear surface of the main body, in which the first film is made of MgO, the second film is made of SiO_2, and the second film is thinner than the first film.

In the electron multiplier, since the second film made of SiO_2 is provided on at least a part of the first film made of MgO, it is possible to suppress deterioration in gain over time during the time of exposure to the atmosphere, for example. In addition, since the second film made of SiO_2 is made thinner than the first film made of MgO, it is possible to allow the first film made of MgO to serve as a main secondary electron multiplier layer while utilizing a characteristic of MgO having a large secondary electron emission coefficient, thereby efficiently improving the gain. Furthermore, since the first film is made of MgO and the second film is made of SiO_2, the gain may be increased from the initial gain after the exposure to the atmosphere. Therefore, it is possible to improve the gain while suppressing the deterioration in gain over time.

In the electron multiplier according to one aspect of the present invention, the second film may be distributed in an island shape on the first film. In this case, it is possible to further improve the gain by allowing the first film to more effectively serve as the secondary electron multiplier layer while sufficiently securing the effect of suppressing the deterioration in gain over time.

In the electron multiplier according to one aspect of the present invention, a thickness of the first film may be 10 Å or more when being calculated by using X-ray fluorescence analysis. If the first film has the thickness of 10 Å or more in this manner, the first film made of MgO may be allowed to effectively serve as the secondary electron multiplier layer.

In the electron multiplier according to one aspect of the present invention, the main body may be made of an insulating material, and a resistance film may be formed between the inner wall surface of the channel and the first film. In this case, a potential gradient is formed by the resistance film when voltage is applied between the electrode layer provided on the front surface of the main body and the electrode layer provided on the rear surface of the main body, and electron multiplication becomes possible.

In the electron multiplier according to one aspect of the present invention, the main body may be made of a resistant material. In this case, it is unnecessary to provide the resistance film on the inner wall surface of the channel, and a manufacturing process of the resistance film may be omitted, so that a manufacturing cost may be reduced.

In the electron multiplier according to one aspect of the present invention, the first film and the second film may be formed on the front surface, the rear surface, and the side surface of the main body, and the electrode layers may be formed on the second film. Alternatively, the electrode layers may be formed so as to be in contact with the front surface and the rear surface of the main body, and the first film and the second film may be formed on the electrode layers, and the front surface, the rear surface, and the side surface of the main body. In these configurations, gas emission from the main body may be effectively suppressed in a case where the main body is made of a material which emits a large amount of gas, for example, since the first film and the second film cover the front surface, the rear surface, and the side surface of the main body.

In the electron multiplier according to one aspect of the present invention, the resistance film, the first film, and the second film may be formed on the front surface, the rear surface, and the side surface of the main body, and the electrode layers may be formed on the second film. Alternatively, the electrode layers may be formed so as to be in contact with the front surface and the rear surface of the main body, and the resistance film, the first film, and the second film may be formed on the front surface, the rear surface, and the side surface of the main body. In these configurations, gas emission from the main body may be effectively suppressed in a case where the main body is made of a material which emits a large amount of gas, for example, since not only the first film and the second film but also the resistance film cover the front surface, the rear surface, and the side surface of the main body.

In the electron multiplier according to one aspect of the present invention, the first film and the second film may be layers formed by atomic layer deposition. In this case, since the first film and the second film may be formed at an atomic layer level, a film in which a defect such as a pinhole is suppressed with a uniform film quality may be formed.

In the microchannel plate according to one aspect of the present invention, the resistance film may be formed by laminating an Al_2O_3layer and a Pt layer alternately. In the microchannel plate according to one aspect of the present invention, the first film may be formed on an Al_2O_3layer.

In the microchannel plate according to one aspect of the present invention, the first film may be formed on a Pt layer.

In the electron multiplier according to one aspect of the present invention, the resistance film may be formed by laminating an Al_2O_3layer and a Pt layer alternately. In the

electron multiplier according to one aspect of the present invention, the first film may be formed on an Al_2O_3layer.

In the electron multiplier according to one aspect of the present invention, the first film may be formed on a Pt layer.

Effects of Invention

According to one aspect of the present invention, it is possible to provide a microchannel plate and an electron multiplier capable of improving the gain while suppressing deterioration in gain over time.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1**(*a*) is a perspective view of a microchannel plate according to a first embodiment.

FIG. **1**(*b*) is a perspective view illustrating a film configuration of the microchannel plate of FIG. **1**(*a*).

FIG. **2** is a flowchart illustrating a film forming process of the microchannel plate of FIG. **1**.

FIG. **3** is a view illustrating a relationship between the number of times of deposition of a SiO_2 layer and a layer thickness of SiO_2.

FIG. **4**(*a*) is a side view conceptually illustrating a structure in which SiO_2 is deposited on an outermost surface of MgO.

FIG. **4**(*b*) is a side view illustrating distribution of SiO_2 in FIG. **4**(*a*).

FIG. **4**(*c*) is a perspective view illustrating the distribution of SiO_2 in FIG. **4**(*a*).

FIG. **5**(*a*) is a side view conceptually illustrating a structure in which SiO_2 is further deposited on the outermost surface of MgO of FIG. **4**.

FIG. **5**(*b*) is a side view illustrating distribution of SiO_2 in FIG. **5**(*a*).

FIG. **5**(*c*) is a perspective view illustrating the distribution of SiO_2 in FIG. **5**(*a*).

FIG. **6**(*a*) is a side view conceptually illustrating a structure in which SiO_2 is further deposited on the outermost surface of MgO of FIG. **5**.

FIG. **6**(*b*) is a side view illustrating distribution of SiO_2 in FIG. **6**(*a*).

FIG. **6**(*c*) is a perspective view illustrating the distribution of SiO_2 in FIG. **6**(*a*).

FIG. **7** is a side view conceptually illustrating a structure in which SiO_2 is further deposited on the outermost surface of MgO of FIG. **6**.

FIG. **8**(*a*) is a view schematically illustrating a bonding structure of the outermost surface of MgO on which SiO_2 is not deposited.

FIG. **8**(*b*) is a view schematically illustrating a bonding structure of the outermost surface of MgO on which SiO_2 is deposited.

FIG. **9** is a graph illustrating a relationship of initial gain with respect to the number of times of deposition of the SiO_2 layer.

FIG. **10** is a flowchart illustrating a film forming process of a microchannel plate of a reference example.

FIG. **11** is a view illustrating a relationship between the number of times of deposition of a SiO_2 layer and gain by this SiO_2.

FIG. **12** is a view illustrating a change in composition of a film due to exposure in the atmosphere.

FIG. **13** is a graph illustrating a change in gain over time due to the exposure in the atmosphere.

FIG. **14** is another graph illustrating the change in gain over time due to the exposure in the atmosphere.

FIG. **15** is a graph illustrating a change in relative gain over time due to the exposure in the atmosphere.

FIG. **16** is a cross-sectional view of an electron multiplier according to a second embodiment.

FIG. **17**(*a*) is a cross-sectional view of a microchannel plate according to a variation.

FIG. **17**(*b*) is a cross-sectional view of an electron multiplier according to the variation.

DESCRIPTION OF EMBODIMENTS

Hereinafter, embodiments according to one aspect of the present invention are described in detail with reference to the accompanying drawings. In the description of the drawings, the same reference sign is assigned to the same or corresponding elements and the description is not repeated.

First Embodiment

FIG. **1**(*a*) is a perspective view of a microchannel plate according to a first embodiment. FIG. **1** illustrates the microchannel plate with a cross-section of a part thereof. As illustrated in FIG. **1**(*a*), a microchannel plate **10** is a member having a function of multiplying electrons. The microchannel plate **10** includes a disc-shaped substrate **11** including an input surface (front surface) **11***a* and an output surface (rear surface) **11***b*. The substrate **11** is made of an insulating material such as soda-lime glass, borosilicate glass, lead glass, an aluminum oxide treated with alumite treatment or the like, for example. A plurality of channels **12** each having a circular cross-section is formed in the substrate **11**. The channel **12** penetrates from the input surface **11***a* to the output surface **11***b* of the substrate **11**. The channels **12** are arranged in a matrix pattern in a plan view such that a center-to-center distance between adjacent channels **12** is, for example, several micrometers to tens of micrometers. A length of the channel **12** in a thickness direction of the microchannel plate **10** is, for example, 430 μm. A diameter of the channel **12** is, for example, 10 μm.

FIG. **1**(*b*) is a perspective view illustrating a film configuration of the microchannel plate of FIG. **1**(*a*). FIG. **1**(*b*) illustrates the film configuration of a cross-section in the thickness direction in the microchannel plate **10**. As illustrated in FIG. **1**(*b*), a resistance film **13**, an electron emission film (first film) **14**, a protection film (second film) **15**, an input electrode (electrode layer) **16**, and an output electrode (electrode layer) **17** are formed on the substrate **11** as functional films.

The resistance film **13** is provided on an inner wall surface **12***a* of the channel **12**. The resistance film **13** is provided so as to cover an outer surface of the substrate **11**. Specifically, the resistance film **13** is formed on at least the inner wall surface **12***a* of the channel **12**. The resistance film **13** is formed on the input surface **11***a* including an edge **11***x* where the channel **12** is not formed. The resistance film **13** is formed on the output surface **11***b* including an edge **11***y* where the channel **12** is not formed. The edges **11***x* and **11***y* are provided, for example, for convenience of handling of the microchannel plate **10**.

In the cross-section illustrated in FIG. **1**(*b*), the resistance film **13** is formed into a rectangular frame shape surrounding the substrate **11**. The resistance film **13** is formed so as to cover a side surface **11***c* of the substrate **11**. The resistance film **13** covers the input surface **11***a*, the output surface **11***b*, the inner wall surface **12***a* of the channel **12**, and the side surface **11***c* in the above-described manner, so that gas emission from the substrate **11** may be effectively sup-

pressed in a case where the substrate **11** is made of the material such as lead glass which emits a large amount of gas during operation, for example. The resistance film has a predetermined resistance value suitable for electron multiplication in the microchannel plate **10**.

The resistance film **13** is formed by using, for example, the atomic layer deposition (ALD). The resistance film **13** is formed, for example, by repeating a cycle of depositing an Al_2O_3 layer and a cycle of depositing a Pt layer by the atomic layer deposition a plurality of times, respectively. A thickness of the resistance film **13** is, for example, about 200 Å to 700 Å.

The atomic layer deposition is a method of repeatedly performing an adsorption process of a molecule of a compound, a film formation process by reaction, and a purge process of removing a surplus molecule, thereby depositing (laminating) atomic layers one by one to obtain a thin film. As a material for forming the electron emission film **14** and the protection film **15**, a metal oxide is used from a viewpoint of obtaining chemical stability. Examples of such metal oxide include Al_2O_3, MgO, BeO, CaO, SrO, BaO, SiO_2, TiO_2, RuO, ZrO, NiO, CuO, GaO, ZnO and the like, for example. According to the atomic layer deposition, since the film is formed at an atomic layer level, a film in which a defect such as a pinhole is suppressed with a uniform film quality may be formed. A mixed film containing a plurality of metal oxides may be formed in the order of angstroms. The mixed film containing a plurality of metal oxides may be formed, for example, for a gap and a trench structure with a high aspect ratio.

The electron emission film **14** is the first film provided on the inner wall surface **12***a* of the channel **12**. The electron emission film **14** is provided so as to cover the resistance film **13**. Specifically, the electron emission film **14** is formed so as to be in contact with the resistance film **13** on at least the inner wall surface **12***a* of the channel **12**. The electron emission film **14** is formed so as to be in contact with the resistance film **13** on the input surface **11***a* including the edge **11***x* where the channel **12** is not formed. The electron emission film **14** is formed so as to be in contact with the resistance film **13** on the output surface **11***b* including the edge **11***y* where the channel **12** is not formed. The electron emission film **14** is formed into a rectangular frame shape so as to surround the resistance film **13** on the cross-section illustrated in FIG. **1**(*b*). The electron emission film **14** is formed so as to cover the side surface **110** of the substrate **11**. The electron emission film **14** covers the input surface **11***a*, the output surface **11***b*, the inner wall surface **12***a* of the channel **12**, and the side surface **11***c* in the above-described manner, so that the gas emission from the substrate **11** may be effectively suppressed in a case where the substrate **11** is made of the material such as lead glass which emits a large amount of gas during operation, for example. When electrons accelerated by an electric field (to be described later) in the channel **12** collide with the electron emission film **14**, the electron emission film **14** emits secondary electrons accordingly and multiplies the electrons.

The electron emission film **14** is made of MgO. The electron emission film **14** is formed by using the atomic layer deposition, for example. The electron emission film **14** is formed, for example, by repeating a cycle of depositing all MgO layer by the atomic layer deposition a plurality of times. In a case of forming the electron emission film **14**, $Mg(Cp)_2$ may be used, for example, as reaction gas. In this case, a process of forming the electron emission film **14** includes an H_2O adsorption process, an H_2O purge process, a $Mg(Cp)_2$ adsorption process, and a $Mg(Cp)_2$ purge process. In the process of forming the electron emission film **14**, a series of processes is repeatedly performed until a desired thickness of the electron emission film **14** is realized.

The thickness of the electron emission film **14** is 10 Å or more. The "thickness of the film" is herein intended to mean a value corresponding to a film thickness calculated on the basis of a signal value regarding presence of an element contained in the film obtained by analyzing the film by using X-ray fluorescence analysis (XRF) (thickness calculated by using the X-ray fluorescence analysis). That is, the thickness of the electron emission film **14** is 10 Å or more in a case where the thickness of the electron emission film **14** is calculated by using the X-ray fluorescence analysis. More preferably, the thickness of the electron emission film **14** is, for example, about 30 Å to 100 Å.

The protection film **15** is the second film provided on at least a part of the electron emission film **14** (first film). The protection film **15** is formed so as to be in contact with the electron emission film **14** on at least a part of the inner wall surface **12***a* of the channel **12**. The protection film **15** is formed so as to be in contact with the electron emission film **14** on at least a part of the input surface **11***a*. The protection film **15** is formed so as to be in contact with the electron emission film **14** on at least a part of the output surface **11***b*. The protection film **15** is formed so as to be in contact with at least a part of the side surface **11***c* of the substrate **11**. The protection film **15** is formed in at least a part of an area in a rectangular frame shape surrounding the electron emission film **14** in the cross-section illustrated in FIG. **1**(*b*). The protection film **15** suppresses deterioration in gain (gain) over time of secondary electron emission when the microchannel plate **10** is exposed to the atmosphere, and increases the gain from initial gain in cooperation with the electron emission film **14** (to be described later in detail). The gain is an index indicating a degree of emission of the secondary electrons in a state in which the film is formed on the channel, for example.

The protection film **15** is made of SiO_2. The protection film **15** is formed by using the atomic layer deposition, for example. The protection film **15** is formed, for example, by repeating a cycle of depositing a SiO_2 layer by the atomic layer deposition a plurality of times. A thickness of the protection film **15** is, for example, a half or less of that of the electron emission film **14**. Preferably, the thickness of the protection film **15** is, for example, 10 Å or less. More preferably, the thickness of the protection film **15** is, for example, about 5 Å to 10 Å. That is, the protection film **15** is thinner than the electron emission film **14**.

The input electrode **16** and the output electrode **17** are provided on the input surface **11***a* and the output surface **11***b* of the substrate **11**, respectively. Specifically, the input electrode **16** is formed so as to be in contact with the protection film **15** on the input surface **11***a* except for the edge **11***x*. The output electrode **17** is formed so as to be in contact with the protection film **15** on the output surface **11***b* except for the edge **11***y*. The input electrode **16** and the output electrode **17** are formed by evaporating an ITO film made of In_2O_3 and SnO_2, a nesa (SnO_2) film, a nichrome film, an Inconel (registered trademark) film or the like, for example. By using evaporation, the input electrode **16** is formed on the input surface **11***a* except for an opening of the channel **12**, and the output electrode **17** is formed on the output surface **11***b* except for the opening of the channel **12**. Thicknesses of the input electrode **16** and the output electrode **17** are, for example, about 1000 Å. Voltage potential which is lower in the output electrode **17** than in the input electrode **16** is applied to the input electrode **16** and the

output electrode **17** such that an electric field directed from the input electrode **16** to the output electrode **17** is generated in the channel **12**.

Herein, in order to specify structures or characteristics of the resistance film **13**, the electron emission film **14**, and the protection film **15** (hereinafter referred to as "ALD film" in this paragraph) formed by the atomic layer deposition, a surface state of the ALD film is necessarily analyzed. However, regarding the ALD film formed on a structure with a high aspect ratio such as the microchannel plate **10**, no device capable of specifically analyzing the surface state thereof is currently known. Therefore, it is difficult to analyze a laminated structure itself of the ALD film. As described above, it is technically impossible or impractical to analyze the structure or the characteristic of the ALD film at the time of filing, so that there is a circumstance that it is impossible or impractical to directly specify the ALD film by its structure or characteristic in the microchannel plate **10**.

Next, a method of manufacturing the microchannel plate **10** is described in detail.

FIG. **2** is a flowchart illustrating a film forming process of the microchannel plate of FIG. **1**(*a*). First, the resistance film **13** is formed on the substrate **11** at steps S**1** to S**3**. Specifically, as illustrated in FIG. **2**, a cycle of depositing the Al_2O_3 layer by using the atomic layer deposition is repeated A times (step S**1**). Subsequently, a cycle of depositing the Pt layer is repeated B times (step S**2**). Steps S**1** and S**2** are repeated C times (step S**3**).

Subsequently, the electron emission film **14** is formed at step S**4**, and thereafter, the protection film **15** is formed on at least a part of the electron emission film **14** at step S**5**. Specifically, a cycle of depositing the MgO layer by using the atomic layer deposition is repeated D times (step S**4**). A cycle of depositing the SiO_2 layer on an outermost surface of MgO by using the atomic layer deposition is repeated X times (step S**5**). As illustrated in FIG. **3**, in a case by using the atomic layer deposition, as the number of times of deposition of the SiO_2 layer at the time of forming a SiO_2 film increases, a thickness of the SiO_2 film (thickness calculated by using the X-ray fluorescence analysis) increases. Herein, as the number of times of deposition of the SiO_2 layer increases by one, the thickness of the SiO_2 film increases by approximately 1 Å. That is, one deposition (one cycle) of the SiO_2 layer corresponds to the thickness of the SiO_2 film of 1 Å. In this manner, it is possible to make the thickness of the SiO_2 film a desired thickness by changing the number of times of deposition of the SiO_2 layer. "Number of times of deposition" means the number of times the cycle of depositing a layer of film forming material is repeated by using the atomic layer deposition.

Subsequently, the input electrode **16** and the output electrode **17** are formed by evaporation and the like. Thereafter, for example, heat treatment and the like are performed to obtain the microchannel plate **10**. Meanwhile, it is also possible to manufacture a microchannel plate **10**A by forming the resistance film **13**, the electron emission film **14**, and the protection film **15** at steps S**1** to S**5** described above after forming an input electrode **16**A and an output electrode **17**A on the substrate **11** in advance by evaporation and the like (refer to FIG. **17**(*a*)). In this case, the input electrode **16**A is formed so as to be in contact with the input surface **11***a* of the substrate **11** and the output electrode **17**A is formed so as to be in contact with the output surface **11***b*, and the resistance film **13**, the electron emission film **14**, and the protection film **15** are sequentially formed so as to cover the input electrode **16**A and the output electrode **17**A. A range in which the resistance film **13**, the electron emission film **14**, and the protection film **15** are formed is as described above, the range which covers the input surface **11***a*, the output surface **11***b*, the inner wall surface **12***a* of the channel **12**, and the side surface **11***c*.

In the microchannel plate **10**, by providing the protection film **15** made of SiO_2 on at least a part of the electron emission film **14** made of MgO, not only the deterioration in gain over time in a case of the exposure to the atmosphere is suppressed but also the gain increases from the initial gain immediately before the exposure to the atmosphere after the exposure to the atmosphere.

A structure of the protection film **15** is described in more detail. The protection film **15** is distributed in an island shape (island shape) on the electron emission film **14**. Herein, a state "distributed in an island shape" includes a state in which SiO_2 forming the protection film **15** is scattered (discretely adsorbed) on MgO forming the electron emission film **14**. The state "distributed in an island shape" includes a state in which the structure of the protection film **15** is a deposited structure in which a plurality of islands is formed on the outermost surface of MgO in a side view. The state "distributed in an island shape" includes a state in which SiO_2 forming the protection film **15** is partially absent on MgO forming the electron emission film **14**. The state "distributed in an island shape" includes a state in which the structure of the protection film **15** is partially opened. The state "distributed in an island shape" includes a state in which SiO_2 forming the protection film **15** is entirely absent on MgO forming the electron emission film **14**. The state "distributed in an island shape" includes a state in which the structure of the protection film **15** is not a continuous layer. The "continuous layer" of the protection film **15** refers to a structure in which the structure of the protection film **15** is not opened and covers an entire (entire surface of) the electron emission film **14**.

When the cycle of depositing SiO_2 on the outermost surface of MgO is carried out, first, as illustrated in FIG. **4**(*a*), SiO_2 is adsorbed to MgO so that SiO_2 is scattered on the outermost surface of MgO. As a result, as illustrated in FIG. **4**(*b*), on the protection film **15**, a gap for exposing the outermost surface of MgO is formed, and the structure of the protection film **15** is partially opened. That is, as illustrated in FIG. **4**(*c*), the protection film **15** is distributed in a sparse island shape on the electron emission film **14**.

Subsequently, when the cycle of depositing SiO_2 on the outermost surface of MgO in FIG. **4** is further carried out, as illustrated in FIG. **5**(*a*), SiO_2 is further adsorbed to SiO_2 already absorbed to the outermost surface of MgO. This increases a thickness of SiO_2 adsorbed to the outermost surface of MgO. In addition, SiO_2 is newly adsorbed to the outermost surface of MgO to which SiO_2 is not adsorbed yet. As a result, as illustrated in FIG. **5**(*b*), the gap for exposing the outermost surface of MgO becomes narrower than that in the example in FIG. **4**(*b*), and a part of the holes of the protection film **15** is filled. That is, as illustrated in FIG. **5**(*c*), the protection film **15** is distributed in a denser island shape than that in the example in FIG. **4**(*c*) on the electron emission film **14**.

Subsequently, when the cycle of depositing SiO_2 on the outermost surface of MgO in FIG. **5** is further carried out, as illustrated in FIG. **6**(*a*), SiO_2 is further adsorbed to SiO_2 already absorbed to the outermost surface of MgO. This further increases the thickness of SiO_2 adsorbed to the outermost surface of MgO. In addition, SiO_2 is newly adsorbed to the outermost surface of MgO to which SiO_2 is not adsorbed yet. As a result, as illustrated in FIG. **6**(*b*), the

gap for exposing the outermost surface of MgO becomes narrower than that in the example in FIG. **5**(*b*), and a part of the holes of the protection film **15** is further filled. That is, as illustrated in FIG. **6**(*c*), the protection film **15** is distributed in a denser island shape than that in the example in FIG. **5**(*c*) on the electron emission film **14** and approaches the continuous layer.

Subsequently, when the cycle of depositing SiO_2 on the outermost surface of MgO in FIG. **6** is further carried out, as illustrated in FIG. **7**, SiO_2 is further adsorbed to SiO_2 covering the outermost surface of MgO and SiO_2 is newly absorbed to the outermost surface of MgO to which SiO_2 is not yet absorbed. As a result, the protection film **15** is distributed in the continuous layer on the electron emission film **14**.

In this manner, by changing the number of times of deposition of the SiO_2layer, it is possible to make the thickness of the SiO_2 film a desired thickness while allowing the protection film **15** to be distributed in an island shape on the electron emission film **14**.

Meanwhile, the protection film **15** may be provided to cover the entire electron emission film **14** and may be distributed in a continuous layer. In this case, the protection film **15** is formed so as to be in contact with the electron emission film **14** on the inner wall surface **12***a* of the channel **12**. The protection film **15** is formed so as to be in contact with the electron emission film **14** on the input surface **11***a*. The protection film **15** is formed so as to be in contact with the electron emission film **14** on the output surface **11***b*. The protection film **15** is formed so as to cover the side surface **11***c* of the substrate **11**. The protection film **15** is formed into the rectangular frame shape so as to surround the electron emission film **14** in the cross-section illustrated in FIG. **1**(*b*).

FIG. **8**(*a*) is a view schematically illustrating a bonding structure of the outermost surface of MgO on which SiO_2 is not deposited. FIG. **8**(*b*) is a view schematically illustrating a bonding structure of the outermost surface of MgO on which SiO_2 is deposited. As illustrated in FIG. **8**(*a*), on the outermost surface of MgO on which SiO_2 is not deposited, there is a bonding structure (reactive site) in which an OH group is bonded to Mg. At the reactive site, H_2O (moisture), CO_2 (carbon dioxide) and the like present in the atmosphere react with MgO to easily generate $MgCO_3$. That is, when the protection film **15** made of SiO_2 is not provided on the electron emission film **14** made of MgO, C (carbon) derived from H_2O and CO_2 present in the atmosphere is likely to be adhered to the outermost surface of MgO. In this point, MgO on which SiO_2 is not deposited is unstable in the atmosphere.

On the other hand, as illustrated in FIG. **8**(*b*), no reactive site exists on the outermost surface of MgO on which SiO_2 is deposited. More specifically, the OH group is bonded to Mg via SiO_2 in place of the bonding structure in which the OH group is directly bonded to Mg. As a result, at a terminal end of the bonding structure on the outermost surface of MgO, it is suppressed that the OH group is directly bonded to Mg to become the reactive site. In other words, there is an end cap structure in which the reactive site is blocked. According to the end cap structure, reaction between H_2O and CO_2 present in the atmosphere with MgO is suppressed and $MgCO_3$ is less likely to be generated as compared to a case where SiO_2 is not deposited on the outermost surface of MgO. That is, when the protection film **15** made of SiO_2 is provided on at least a part of the electron emission film **14** made of MgO, C (carbon) derived from H_2O and CO_2 present in the atmosphere is not likely to be adhered to the outermost surface of MgO. In this respect, SiO_2 is stable in the atmosphere. In this manner, by allowing the SiO_2 layer stable in the atmosphere to absorb to the outermost surface of MgO susceptible to be unstable in the atmosphere, MgO may be stabilized even in the atmosphere.

Next, a characteristic of the gain of the microchannel plate **10** is described.

In the following description, as an example, the microchannel plate **10** manufactured by forming the protection film **15** by depositing the SiO_2 layer X times (5, 10, and 20 times) on the electron emission film **14** formed by depositing the MgO layer D times (30 times) in the method of manufacturing the microchannel plate **10** illustrated in FIG. **2** was prepared. Also, a microchannel plate in which no SiO_2 film is formed on the electron emission film **14** was prepared. The microchannel plates **10** obtained by depositing the SiO_2 layer X times (5, 10, and 20 times) are made examples 1, 2, and 3, respectively. The microchannel plate in which the SiO_2 film is not formed on the electron emission film **14** is made a comparative example.

First, a characteristic of the initial gain of the microchannel plate **10** is described. The initial gain is the gain immediately before the microchannel plate **10** is exposed to the atmosphere after being stored in N_2 until the gain becomes stable after the manufacture thereof.

FIG. **9** is a graph illustrating a relationship of the initial gain with respect to the number of times of deposition of the SiO_2 layer. As illustrated in FIG. **9**, the initial gain when the protection film **15** is formed on the electron emission film **14** (examples 1, 2, and 3) decreases as the number of times of deposition of the SiO_2 layer increases as compared to the initial gain in a case where the protection film **15** is not formed on the electron emission film **14** (comparative example). Meanwhile, in FIGS. **9** and **12** to **15**, the representation "only MgO" means the microchannel plate in which the protection film **15** made of SiO_2 is not provided on the electron emission film **14** made of MgO (that is, the microchannel plate of only the electron emission film **14** made of MgO). The representation "MgO+SiO_2 (deposition of n times)" means the microchannel plate in which the protection film **15** made of the SiO_2 layer with the number of times of deposition of "n" is provided on at least a part of the electron emission film **14** made of MgO.

This decreasing tendency of the initial gain is considered in consideration of magnitude of secondary electron emission coefficients of the electron emission film **14** and the protection film **15**. Meanwhile, in the following description, the secondary electron emission coefficient is an index indicating a degree of emission of the secondary electrons when focusing on the film itself.

The initial gain increases or decreases according to the secondary electrons emitted from the electron emission film **14** made of MgO and the secondary electrons emitted from the protection film **15** made of SiO_2. Herein, it was examined whether the protection film **15** made of SiO_2 serves as an electron emission film which emits the secondary electrons. A microchannel plate of the following reference example was used in this examination.

FIG. **10** is a flowchart illustrating a film forming process of the microchannel plate of the reference example. In the microchannel plate of the reference example, only a protection film is formed on a substrate **11** on which a resistance film is formed without forming an electron emission film. As illustrated in FIG. **10**, a cycle of depositing an Al_2O_3 layer by using the atomic layer deposition is repeated A times as at step S**1** of the film forming process illustrated in FIG. **2**. Subsequently, in place of step S**2** of depositing a Pt layer in FIG. **2**, a cycle of depositing a TiO_2 layer by using the atomic layer deposition was repeated B times (step S**2**').

Steps S1 and S2' are repeated C times (step S3). Subsequently, step S4 in the film forming process illustrated in FIG. **2** is skipped, and the protection film was formed on the TiO_2 layer by depositing the SiO_2 layer X times (3, 5, 7, 10, 12, 15, 17,25, and 34 times) without forming the MgO layer (step S5').

FIG. **11** is a view illustrating a relationship between the number of times of deposition of the SiO_2 layer and gain by the SiO_2 layer in the microchannel plate of the reference example. In FIG. **11**, the gain of the microchannel plate of the reference example is plotted along the ordinate. As illustrated in FIG. **11**, it may be understood that the gain of the SiO_2 layer tends to increase as the number of times of deposition of the SiO_2 layer increases (as the thickness of the protection film increases).

However, the gain of this SiO_2 layer is smaller than the gain of the MgO layer. As an example of the gain of the MgO layer, the initial gain of the microchannel plate of the comparative example is about 10000 (refer to FIG. **9**), whereas the magnitude of the gain of the SiO_2 layer is about 100 even in a case where the number of times of deposition of the SiO_2 layer is 20. Therefore, it is understood that, in the microchannel plate **10**, the electron emission film **14** made of MgO serves as a main secondary electron multiplier layer. In this manner, in the microchannel plate **10**, contribution of the protection film **15** made of SiO_2 to the secondary electron multiplication is smaller than the contribution of the electron emission film **14** made of MgO to the secondary electron multiplication. It may also be said that the protection film **15** serves as an electron non-emission film which does not substantially emit the secondary electrons.

According to the above-described consideration, in the microchannel plate **10**, an effect is easily exhibited as the thickness of the protection film **15** increases, wherein the effect is that the emission of the secondary electrons from the electron emission film **14** is blocked by the protection film **15** which does not substantially emit the secondary electrons. Therefore, in the example of FIG. **9**, it is considered that the initial gain decreases as the thickness of the protection film **15** increases.

Therefore, in the microchannel plate **10**, it is considered that the characteristic of MgO having a large secondary electron emission coefficient may be utilized and the gain may be efficiently improved when the protection film **15** is made thin (for example, less than 10 Å) and the electron emission film **14** made of MgO is allowed to serve as the main secondary electron multiplier layer as compared to a case where the protection film **15** is made thicker (for example, 10 Å or more) and the secondary electron emission coefficient of the protection film **15** is increased. Therefore, in the microchannel plate **10**, the thickness of the protection film **15** may be less than 10 Å. Especially, in the microchannel plate **10**, the thickness of the protection film **15** may be 5 Å to 10 Å. By optimizing the thickness of the SiO_2 layer to be adsorbed in this manner, the electron emission film **14** made of MgO may be allowed to effectively serve as the secondary electron multiplier layer to maintain the high gain while sufficiently securing the effect of suppressing the deterioration in gain over time.

Next, a changing characteristic over time of the gain when the microchannel plate **10** is exposed to the atmosphere is described.

FIG. **12** is a view illustrating a change in composition of the film due to the exposure to the atmosphere. FIG. **12** illustrates a result of analyzing the change in composition of the film when the electron emission film **14** made of MgO and the protection film **15** made of SiO_2 are exposed to the atmosphere by X-ray photoelectron spectroscopy (XPS). The X-ray photoelectron spectroscopy is a technology of obtaining elemental composition and elemental bonding information of an area near a surface of a measurement target by detecting an energy spectrum of photoelectrons excited and emitted when X-rays are allowed to be incident on the measurement target. Herein, X-ray photoelectron spectroscopy was performed by using μ-XPS (μ-ESCA) as an X-ray photoelectron spectrometer, setting a depth of an area to be analyzed to the outermost layer (0 to several nm), using Al-Ka (1486.6 eV) as an X-ray source, setting a tube voltage to 15 kV, and setting an output to 400 W. Meanwhile, in the example of FIG. **12**, in order to simplify the experiment, a predetermined metal plate was used in place of the substrate **11**, and the electron emission film **14** made of MgO and the protection film **15** made of SiO_2 were formed on this metal plate.

As illustrated in FIG. **12**, when the protection film **15** made of SiO_2 is not provided on the electron emission film **14** made of MgO, a ratio of $MgO:MgCO_3$ after the exposure to the atmosphere was 57:43. That is, it is inferred that C (carbon) derived from H_2O and CO_2 present in the atmosphere adheres to the outermost surface of MgO. As described above, it is considered that this is because there is the bonding structure (reactive site) in which the OH group is bonded to Mg on the outermost surface of MgO.

On the other hand, in a case where the protection film **15** made of SiO_2 is provided on at least a part of the electron emission film **14** made of MgO, the ratio of $MgO:MgCO_3$ after the exposure to the atmosphere is 86:14 when the number of times of deposition of the SiO_2 layer is five, and 87:13 when the number of times of deposition of the SiO_2 layer is ten. That is, the adhesion of C derived from H_2O and CO_2 present in the atmosphere to the outermost surface of MgO is suppressed. This is because, as described above, the OH group is bonded to Mg via SiO_2 in place of the bonding structure in which the OH group is directly bonded to Mg and the end cap structure in which the reactive site is blocked is realized. From the above results, in the microchannel plate **10**, the protection film **15** made of SiO_2 is provided on at least a part of the electron emission film **14** made of MgO, so that the electron emission film **14** made of MgO which serves as the main secondary electron multiplier layer is allowed to be stabilized even in the atmosphere and the deterioration in gain over time during the time of the exposure to the atmosphere is suppressed.

FIG. **13** is a graph illustrating a change in gain over time due to the exposure to the atmosphere. FIG. **14** is another graph illustrating the change in gain over time due to the exposure to the atmosphere. FIG. **15** is a graph illustrating a change in relative gain over time due to the exposure to the atmosphere. FIGS. **13** to **15** illustrate measurement results of the change in gain over time for the microchannel plate **10** exposed to the atmosphere after being stored in N_2 until the gain is stabilized after the manufacture thereof. In FIGS. **13** and **14**, the gain of the microchannel plate is plotted along the ordinate. In FIG. **15**, a relative change rate of the gain (relative gain) with reference to the gain (initial gain) of the microchannel plate **10** immediately before the exposure to the atmosphere (0 days elapsed) is plotted along the ordinate.

In the example of FIG. **13**, points indicating the gain when the microchannel plates **10** of the examples 1, 2, and 3 and the microchannel plate of the comparative example are exposed for 0 and 3 days are plotted. In the example of FIG. **14**, regarding the examples 1 and 2, the points indicating the gain when the microchannel plate **10** is exposed for 0, 3, 7,

21, and 29 days are plotted. In the example of FIG. **15**, regarding the examples 1, 2, and 3, the points indicating the relative gain when the microchannel plate **10** is exposed for 0, 3, 7, 21, and 29 days are plotted.

As illustrated in FIG. **13**, in the comparative example in which the protection film **15** made of SiO_2 is not provided on the electron emission film **14** made of MgO, the gain decreases from the initial gain when the microchannel plate **10** is exposed to the atmosphere. On the other hand, in the examples 1, 2, and 3 in which the protection film **15** of SiO_2 is provided on the electron emission film **14** of MgO, the decrease in gain during the time of the exposure to the atmosphere is suppressed. Instead, in the examples 1, 2, and 3, the gain increases from the initial gain after the exposure to the atmosphere.

As illustrated in FIGS. **14** and **15**, it is understood that, in the examples 1 and 2 in which the number of times of deposition of the SiO_2 layer is five and 10, respectively, the gain increased after the exposure to the atmosphere is maintained even after the increase. In the examples 1 and 2, the change in gain over time after the exposure to the atmosphere is smaller than that in the example 3. Meanwhile, the change in gain over time is larger in the example 3 than that in the examples 1 and 2, but since the initial gain of the example 3 is smaller than the initial gain of the examples 1 and 2, an absolute value of the gain in the examples 1 and 2 is larger than that in the example 3.

Action and Effect

In the microchannel plate **10**, the protection film **15** made of SiO_2 is provided on at least a part of the electron emission film **14** made of MgO. Therefore, the reactive site on the outermost surface of MgO may be suppressed, and the electron emission film **14** may be stabilized even in the atmosphere. For example, even in a case of the exposure to the atmosphere, the adhesion of C to the outermost surface of MgO may be suppressed. As a result, it is possible to suppress the deterioration in gain over time during the time of the exposure to the atmosphere. In addition, since the protection film **15** made of SiO_2 is made thinner than the electron emission film **14** made of MgO, it is possible to allow the electron emission film **14** made of MgO to serve as the main secondary electron multiplier layer while utilizing the characteristic of MgO having the large secondary electron emission coefficient, thereby efficiently improving the gain. Furthermore, since the electron emission film **14** is made of MgO and the protection film **15** is made of SiO_2, the gain may be increased from the initial gain after the exposure to the atmosphere. As described above, according to the microchannel plate **10**, a synergetic effect that the adhesion of C to the outermost surface of MgO is suppressed, and the gain is increased from the initial gain is exhibited. Therefore, it is possible to improve the gain while suppressing the deterioration in gain over time.

Meanwhile, although it is conceivable to use diamond as a material of the film of the secondary electron multiplier layer, in this case, it is difficult to form the film for the gap and trench structure of high aspect ratio such as the microchannel plate **10**, and this is not realistic. Also, for example, in a case of using an oxide or nitride unstable in the atmosphere as the material of the film of the secondary electron multiplier layer, it is necessary to form a film in vacuum by using equipment such as a glove box, but in the microchannel plate **10**, it is not necessary to use the equipment such as the glove box.

In the microchannel plate **10**, the protection film **15** is distributed in an island shape on the electron emission film **14**. As a result, the protection film **15** may be made sufficiently thin, and it becomes possible to further improve the gain by allowing the electron emission film **14** to more effectively serve as the secondary electron multiplier layer while sufficiently securing the effect of suppressing the deterioration in gain over time.

A thickness of the electron emission film **14** is 10 Å or more when being calculated by using the X-ray fluorescence analysis. Since the electron emission film **14** made of MgO has the thickness of 10 Å or more as described above, the electron emission film **14** may be allowed to effectively serve as the secondary electron multiplier layer.

The substrate **11** is made of the insulating material, and the resistance film **13** is formed between the inner wall surface **12***a* of the channel **12** and the electron emission film **14**. As a result, when voltage is applied between the input electrode **16** provided on the input surface **11***a* of the substrate **11** and the output electrode **17** provided on the output surface **11***b* of the substrate **11**, a potential gradient is formed by the resistance film **13**, and electron multiplication becomes possible.

The electron emission film **14** and the protection film **15** are formed on the input surface **11***a*, the output surface **11***b*, and the side surface **11***e* of the substrate **11**, and the input electrode **16** and the output electrode **17** are formed on the protection film **15**. Alternatively, an input electrode **16**A is formed so as to be in contact with the input surface **11***a* of the substrate **11** and an output electrode **17**A is formed so as to be in contact with the output surface **11***b*, and the electron emission film **14** and the protection film **15** are formed on the input electrode **16**A and the output electrode **17**A, and the input surface **11***a*, the output surface **11***b*, and the side surface **11***e* of the substrate **11**. In such configurations, the gas emission from the substrate **11** may be effectively suppressed in a case where the substrate **11** is made of a material which emits a large amount of gas, for example, since the electron emission film **14** and the protection film **15** cover the input surface **11***a*, the output surface **11***b*, and the side surface **11***c* of the substrate **11**.

The resistance film **13**, the electron emission film **14**, and the protection film **15** are formed on the input surface **11***a*, the output surface **11***b*, and the side surface **11***c* of the substrate **11**, and the input electrode **16** and the output electrode **17** are formed on the protection film **15**. Alternatively, the input electrode **16**A is formed so as to be in contact with the input surface **11***a* of the substrate **11** and the output electrode **17**A is formed so as to be in contact with the output surface **11***b*, and the resistance film **13**, the electron emission film **14**, and the protection film **15** are formed on the input surface **11***a*, the output surface **11***b*, and the side surface **11***c* of the substrate **11**. In such configurations, the gas emission from the substrate **11** may be effectively suppressed in the case where the substrate **11** is made of the material which emits a large amount of gas, for example, since not only the electron emission film **14** and the protection film **15** but also the resistance film **13** cover the input surface **11***a*, the output surface **11***b*, and the side surface **11***c* of the substrate **11**.

The electron emission film **14** and the protection film **15** are layers formed by the atomic layer deposition. As a result, since the electron emission film **14** and the protection film **15** may be formed at the atomic layer level, the film in which the defect such as the pinhole is suppressed with the uniform film quality may be formed. A mixed film containing a plurality of metal oxides (for example, MgO and SiO_2) may

be formed in the order of angstroms. For example, it is possible to form the film for the gap and the trench structure with the high aspect ratio such as the microchannel plate **10**.

Meanwhile, when the protection film **15** made of SiO_2 is provided on at least a part of the electron emission film **14** made of MgO, C (carbon) derived from H_2O and CO_2 present in the atmosphere is not likely to be adhered to the outermost surface of MgO as compared to a case where the protection film **15** is not provided on the electron emission film **14**. Therefore, the decrease in gain caused by C adhering to the outermost surface of MgO after the exposure to the atmosphere is less likely to occur. In addition, since the protection film **15** is made of SiO_2, even if C adheres to the protection film **15** after the exposure to the atmosphere, the decrease in gain such as that when C adheres to the outermost surface of MgO does not occur, but the gain increases from the initial gain instead. That is, the protection film **15** which is the second film is a film to which C (carbon) due to H_2O and CO_2 present in the atmosphere is less likely to adhere than the electron emission film **14** which is the first film, the film that increases the gain from the initial gain while suppressing the decrease in gain after the exposure to the atmosphere.

Variation of Microchannel Plate **10**

Although the substrate **11** is made of the insulating material in the above-described embodiment, the substrate **11** may also be made of a semiconductor material (resistant material) such as Si. In this case, it is not necessary to provide the resistance film **13** on the inner wall surface **12***a* of the channel **12**, and the electron emission film **14** may also be formed directly on the substrate **11** (formed at least on the inner wall surface **12***a*). Even in such a mode, an action and an effect similar to those of the above-described embodiment may be obtained. Since a manufacturing process of the resistance film **13** may be omitted, a manufacturing cost may be decreased.

Second Embodiment

FIG. **16** is a cross-sectional view of an electron multiplier according to a second embodiment. As illustrated in FIG. **16**, an electron multiplier **20** is a dynode structure having a function to multiply electrons. The electron multiplier **20** includes a main body **21** including one end face (front surface) **21***a* and the other end face (rear surface) **21***b*. The main body **21** has a rectangular parallelepiped shape and extends in a first direction D**1**. The main body **21** is made of an insulating material such as ceramic, for example. Meanwhile, the electron multiplier **20** is not limited to this example, and may also be a dynode structure of a so-called single channel dynode (for example, a channeltron and the like).

A channel **22** is formed in the main body **21**. The channel **22** opens on one end face **21***a* and the other end face **21***b* of the main body **21** in the first direction D**1**. That is, the channel **22** penetrates from the one end face **21***a* to the other end face **21***b* of the main body **21**. A side of the one end face **21***a* of the channel **22** has a tapered shape expanding toward the one end face **21***a*. The channel **22** extends in a wave shape such that bending is repeated in a second direction D**2** from the one end face **21***a* side to the other end face **21***b*. In the channel **22**, electrons are incident and secondary electrons are emitted according to the incident electrons on the one end face **21***a* side, and the secondary electrons are emitted from the other end face **21***b* side.

A resistance film **23**, an electron emission film (first film) **24**, a protection film (second film) **25**, an input electrode (electrode layer) **26**, and an output electrode (electrode layer) **27** are formed on the main body **21** as functional films.

The resistance film **23** is provided on an inner wall surface **22***a* of the channel **22**. The resistance film **23** is provided so as to cover an outer surface of the main body **21**. Specifically, the resistance film **23** is formed at least on the inner wall surface **22***a* of the channel **22**. The resistance film **23** is formed on the one end face **21***a* except for the opening of the channel **22**. The resistance film **23** is formed on the other end face **21***b* except for the opening of the channel **22**. The resistance film **23** is formed so as to cover a side surface **21***c* of the main body **21**. Since the resistance film **23** covers the one end face **21***a*, the other end face **21***b*, the inner wall surface **22***a* of the channel **22**, and the side surface **21***c* in the above-described manner, gas emission from the main body **21** may be effectively suppressed in a case where the main body **21** is made of a material such as lead glass which emits a large amount of gas during operation, for example. The resistance film **23** has a predetermined resistance value suitable for electron multiplication in the electron multiplier **20**. The resistance film **23** is formed, for example, by using atomic layer deposition in a manner similar to that of the resistance film **13**. The resistance film **23** is formed, for example, by repeating a cycle of depositing an Al_2O_3 layer and a cycle of depositing a Pt layer by the atomic layer deposition a plurality of times respectively. A thickness of the resistance film **23** is, for example, about 200 Å to 700 Å.

The electron emission film **24** is the first film provided on the inner wall surface **22***a* of the channel **22**. The electron emission film **24** is provided so as to cover the resistance film **23**. Specifically, the electron emission film **24** is formed so as to be in contact with the resistance film **23** on at least the inner wall surface **22***a* of the channel **22**. The electron emission film **24** is formed so as to be in contact with the resistance film **23** on the one end face **21***a* except for the opening of the channel **22**. The electron emission film **24** is formed so as to be in contact with the resistance film **23** on the other end face **21***b* except for the opening of the channel **22**. The electron emission film **24** is formed so as to cover the side surface **21***c* of the main body **21**. Since the electron emission film **24** covers the one end face **21***a*, the other end face **21***b*, the inner wall surface **22***a* of the channel **22**, and the side surface **21***c* in the above-described manner, the gas emission from the main body **21** may be effectively suppressed in the case where the main body **21** is made of the material such as lead glass which emits a large amount of gas during operation, for example. When electrons accelerated by an electric field (to be described later) in the channel **22** collide with the electron emission film **24**, this emits the secondary electrons accordingly and multiplies the electrons. The electron emission film **24** is made of MgO. The electron emission film **24** is formed, for example, by using the atomic layer deposition in a manner similar to that of the electron emission film **14**. The electron emission film **24** is formed, for example, by repeating a cycle of depositing a MgO layer by the atomic layer deposition a plurality of times. A thickness of the electron emission film **24** is 10 Å or more in a case where the thickness of the electron emission film **24** is calculated by using X-ray fluorescence analysis. The thickness of the electron emission film **24** may also be, for example, about 30 Å to 50 Å.

The protection film **25** is the second film provided on at least a part of the electron emission film **24** (first film). The protection film **25** is formed so as to be in contact with the electron emission film **24** on at least a part of the inner wall

surface **22***a* of the channel **22**. The protection film **25** is formed so as to be in contact with the electron emission film **24** on at least a part of one end face **21***a* except for the opening of the channel **22**. The protection film **25** is formed so as to be in contact with the electron emission film **24** on at least a part of the other end face **21***b* except for the opening of the channel **22**. The protection film **25** is formed so as to be in contact with at least a part of the side surface **21***c* of the main body **21**. The protection film **25** suppresses deterioration in gain over time of secondary electron emission when the electron multiplier **20** is exposed to the atmosphere, and increases the gain from initial gain in cooperation with the electron emission film **24**.

The protection film **25** is made of SiO_2. The protection film **25** is formed, for example, by using the atomic layer deposition in a manner similar to that of the protection film **15**. The protection film **25** is formed, for example, by repeating a cycle of depositing the SiO_2 layer by the atomic layer deposition a plurality of times. A thickness of the protection film **25** is, for example, a half or less of that of the electron emission film **24**. Preferably, the thickness of the protection film **25** is, for example, 10 Å or less. More preferably, the thickness of the protection film **25** is, for example, about 5 Å to 10 Å. That is, the protection film **25** is thinner than the electron emission film **24**.

The input electrode **26** and the output electrode **27** are provided on the one end face **21***a* and the other end face **21***b* of the main body **21**, respectively. Specifically, the input electrode **26** is formed so as to be in contact with the protection film **25** on the one end face **21***a* except for the opening of the channel **22**. The output electrode **27** is formed so as to be in contact with the protection film **25** on the other end face **21***b* except for the opening of the channel **22**. The input electrode **26** and the output electrode **27** are formed by evaporating, for example, a metal film containing nickel-based metal and the like. By using the evaporation, the input electrode **26** is formed on the one end face **21***a* except for the opening of the channel **22**, and the output electrode **27** is formed on the other end face **21***b* except for the opening of the channel **22**. Thicknesses of the input electrode **26** and the output electrode **27** are, for example, about 1000 Å. Voltage potential which is lower in the output electrode **27** than in the input electrode **26** is applied to the input electrode **26** and the output electrode **27** such that an electric field directed from the input electrode **26** to the output electrode **27** is generated in the channel **22**.

Herein, in order to specify structures or characteristics of the resistance film **23**, the electron emission film **24**, and the protection film **25** (hereinafter referred to as "ALD film" in this paragraph) fanned by the atomic layer deposition, it is necessary to analyze a surface state of the ALD film. However, the electron multiplier **20** also is a structure having a high aspect ratio similar to a microchannel plate **10**, and no device capable of specifically analyzing the surface state of the ALD film formed on the electron multiplier **20** is currently known, so that it is difficult to analyze a laminated structure itself of the ALD film. As described above, it is technically impossible or impractical to analyze the structure or the characteristic of the ALD film at the time of filing, so that there is a circumstance that it is impossible or impractical to directly specify the ALD film by its structure or characteristic in the electron multiplier **20**.

Next, a method of manufacturing the electron multiplier **20** is described. As illustrated in FIG. **2**, the method of manufacturing the electron multiplier **20** is such that the resistance film **23** is formed on the main body **21** at steps S**1** to S**3**, the electron emission film **24** is formed on the resistance film **23** at step S**4**, and thereafter, the protection film **25** is formed on at least a part of the electron emission film **24** at step **55**. Since the specific description is similar to that of the method of manufacturing the microchannel plate **10** described above, this is omitted. Meanwhile, it is also possible to manufacture an electron multiplier **20**A by forming the resistance film **23**, the electron emission film **24**, and the protection film **25** at steps S**1** to S**5** described above after an input electrode **26**A and an output electrode **27**A are formed on the main body **21** in advance by evaporation and the like (refer to FIG. **17**(*b*)). In this case, the input electrode **26**A is foamed so as to be in contact with the one end face **21***a* of the main body **21** and the output electrode **27**A is formed so as to be in contact with the other end face **21***b*, and the resistance film **23**, the electron emission film **24**, and the protection film **25** are sequentially fainted so as to cover the input electrode **26**A and the output electrode **27**A. A range in which the resistance film **23**, the electron emission film **24**, and the protection film **25** are formed is as already described above, the range which covers the one end face **21***a*, the other end face **21***b*, the inner wall surface **22***a*, and the side surface **21***c*.

In the electron multiplier **20**, by providing the protection film **25** made of SiO_2 on at least a part of the electron emission film **24** made of MgO, not only the deterioration in gain over time in a case of exposure to the atmosphere is suppressed but also the gain increases from initial gain immediately before the exposure to the atmosphere after the exposure to the atmosphere.

Similar to the protection film **15**, the protection film **25** is distributed in an island shape (island shape) on the electron emission film **24**. Herein, a state "distributed in an island shape" includes a state in which SiO_2 forming the protection film **25** is scattered (discretely adsorbed) on MgO forming the electron emission film **24**. The state "distributed in an island shape" includes a state in which the structure of the protection film **25** is a deposited structure in which a plurality of islands is formed on the outermost surface of MgO in a side view. The state "distributed in an island shape" includes a state in which SiO_2 forming the protection film **25** is partially absent on MgO forming the electron emission film **24**. The state "distributed in an island shape" includes a state in which the structure of the protection film **25** is partially opened. The state "distributed in an island shape" includes a state in which SiO_2 forming the protection film **25** is entirely absent on MgO forming the electron emission film **24**. The state "distributed in an island shape" includes a state in which the structure of the protection film **25** is not a continuous layer. Herein, the "continuous layer" of the protection film **25** refers to a structure in which the structure of the protection film **25** is not opened and covers an entire (entire surface of) the electron emission film **24**.

Meanwhile, the protection film **25** may be provided to cover the entire electron emission film **24** and may be distributed in a continuous layer. In this case, the protection film **25** is formed so as to be in contact with the electron emission film **24** on the inner wall surface **22***a* of the channel **22**. The protection film **25** is formed so as to be in contact with the electron emission film **24** on one end face **21***a* except for the opening of the channel **22**. The protection film **25** is formed so as to be in contact with the electron emission film **24** on the other end face **21***b* except for the opening of the channel **22**. The protection film **25** is formed so as to cover the side surface **21***c* of the main body **21**.

As a result, the electron multiplier **20** has a characteristic similar to that of the microchannel plate **10** as described above.

Specifically, since the protection film **25** made of SiO_2 is provided on at least a part of the electron emission film **24** made of MgO, there is a characteristic that C (carbon) derived from H_2O and CO_2 present in the atmosphere is not likely to be adhered to the outermost surface of MgO.

In the electron multiplier **20** also, it is considered that an effect is easily exhibited as the thickness of the protection film **25** increases, wherein the effect is that the emission of the secondary electrons from the electron emission film **24** is blocked by the protection film **25** which does not substantially emit the secondary electrons. Therefore, in the electron multiplier **20**, it is considered that the characteristic of MgO having a large secondary electron emission coefficient may be utilized and the gain may be efficiently improved when the protection film **25** is made thin (for example, less than 10 Å) and the electron emission film **24** made of MgO is allowed to serve as the main secondary electron multiplier layer as compared to a case where the protection film **25** is made thicker (for example, 10 Å or more) and the secondary electron emission coefficient of the protection film **25** is increased. Therefore, in the electron multiplier **20**, the thickness of the protection film **25** may be less than 10 Å. Especially, in the electron multiplier **20**, the thickness of the protection film **25** may be 5 Å to 10 Å. By optimizing the thickness of the SiO_2 layer to be adsorbed in this manner, the electron emission film **24** made of MgO may be allowed to effectively serve as the secondary electron multiplier layer to maintain the high gain while sufficiently securing the effect of suppressing the deterioration in gain over time.

In the electron multiplier **20** also, when the protection film **25** made of SiO_2 is provided on at least a part of the electron emission film **24** made of MgO, the deterioration in gain during the time of the exposure to the atmosphere is suppressed. Instead, in this case, the gain increases from the initial gain immediately before the exposure to the atmosphere after the exposure to the atmosphere. Also, when the number of times of deposition of the SiO_2 layer is five and **10**, respectively, the gain increased after the exposure to the atmosphere is maintained even after the increase.

Action and Effect

The electron multiplier **20** configured in the above-described manner exhibits an action and an effect similar to those of the microchannel plate **10**. That is, the protection film **25** made of SiO_2 is provided on at least a part of the electron emission film **24** made of MgO. Therefore, the reactive site on the outermost surface of MgO may be suppressed, and the electron emission film **14** may be stabilized even in the atmosphere. For example, even in a case of the exposure to the atmosphere, the adhesion of C to the outermost surface of MgO may be suppressed. As a result, it is possible to suppress the deterioration in gain over time during the time of the exposure to the atmosphere. In addition, since the protection film **25** made of SiO_2 is made thinner than the electron emission film **24** made of MgO, it is possible to allow the electron emission film **24** made of MgO to serve as the main secondary electron multiplier layer while utilizing the characteristic of MgO having the large secondary electron emission coefficient, thereby efficiently improving the gain. Furthermore, since the electron emission film **24** is made of MgO and the protection film **25** is made of SiO_2, the gain may be increased from the initial gain after the exposure to the atmosphere. In this manner, according to the electron multiplier **20**, a synergetic effect that the adhesion of C and O to the outermost surface of MgO is suppressed, and the gain is increased from the initial gain is exhibited. Therefore, it is possible to improve the gain while suppressing the deterioration in gain over time.

In the electron multiplier **20**, the protection film **25** is distributed in an island shape on the electron emission film **24**. As a result, the protection film **25** may be made sufficiently thin, and it becomes possible to further improve the gain by allowing the electron emission film **24** to more effectively serve as the secondary electron multiplier layer while sufficiently securing the effect of suppressing the deterioration in gain over time.

A thickness of the electron emission film **24** is 10 Å or more when being calculated by using the X-ray fluorescence analysis. Since the electron emission film **24** made of MgO has the thickness of 10 Å or more as described above, the electron emission film **24** may be allowed to effectively serve as the secondary electron multiplier layer.

The main body **21** is made of an insulating material, and the resistance film **23** is formed between the main body **21** (inner wall surface **22***a* of the channel **22**) and the electron emission film **24**. As a result, when voltage is applied between the input electrode **26** provided on the one end face **21***a* of the main body **21** and the output electrode **27** provided on the other end face **21***b* of the main body **21**, a potential gradient is formed by the resistance film **23**, and electron multiplication becomes possible.

The electron emission film **24** and the protection film **25** are formed on the one end face **21***a*, the other end face **21***b*, and the side surface **21***c* of the main body **21**, and the input electrode **26** and the output electrode **27** are formed on the protection film **25**. Alternatively, the input electrode **26**A is formed so as to be in contact with the one end face **21***a* of the main body **21** and the output electrode **27**A is formed so as to be in contact with the other end face **21***b*, and the electron emission film **24** and the protection film **25** are formed on the input electrode **26**A and the output electrode **27**A, and the one end face **21***a*, the other end face **21***b*, and the side surface **21***c* of the main body **21**. In such configurations, the gas emission from the main body **21** may be effectively suppressed in a case where the main body **21** is made of a material which emits a large amount of gas, for example, since the electron emission film **24** and the protection film **25** cover the one end face **21***a*, the other end face **21***b*, and the side surface **21***c* of the main body **21**.

The resistance film **23**, the electron emission film **24**, and the protection film **25** are formed on the one end face **21***a*, the other end face **21***b*, and the side surface **21***c* of the main body **21**, and the input electrode **26** and the output electrode **27** are formed on the protection film **25**. Alternatively, the input electrode **26**A is formed so as to be in contact with the one end face **21***a* of the main body **21** and the output electrode **27**A is formed so as to be in contact with the other end face **21***b*, and the resistance film **23**, the electron emission film **24**, and the protection film **25** are formed on the one end face **21***a*, the other end face **21***b*, and the side surface **21***c* of the main body **21**. In such configurations, the gas emission from the main body **21** may be effectively suppressed in the case where the main body **21** is made of the material which emits a large amount of gas, for example, since not only the electron emission film **24** and the protection film **25** but also the resistance film **23** cover the one end face **21***a*, the other end face **21***b*, and the side surface **21***c* of the main body **21**.

The electron emission film **24** and the protection film **25** are layers formed by the atomic layer deposition. As a result, since the electron emission film **24** and the protection film **25** may be formed at an atomic layer level, the film in which a

defect such as a pinhole is suppressed with a uniform film quality may be formed. A mixed film containing a plurality of metal oxides (for example, MgO and SiO_2) may be formed in the order of angstroms. For example, it is possible to form a film for a gap and a trench structure with a high aspect ratio such as the electron multiplier **20**.

Meanwhile, when the protection film **25** made of SiO_2 is provided on at least a part of the electron emission film **24** made of MgO, C (carbon) derived from H_2O and CO_2 present in the atmosphere is not likely to be adhered to the outermost surface of MgO as compared to a case where the protection film **25** is not provided on the electron emission film **24**. Therefore, the decrease in gain caused by C adhering to the outermost surface of MgO after the exposure to the atmosphere is less likely to occur. In addition, since the protection film **25** is made of SiO_2, even if C adheres to the protection film **25** after the exposure to the atmosphere, the decrease in gain such as that when C adheres to the outermost surface of MgO does not occur, but the gain increases from the initial gain instead. That is, the protection film **25** which is the second film is a film to which C (carbon) due to H_2O and CO_2 present in the atmosphere is less likely to adhere than the electron emission film **24** which is the first film, the film that increases the gain from the initial gain while suppressing the decrease in gain after the exposure to the atmosphere.

Variation of Electron Multiplier **20**

Although the main body **21** is made of the insulating material in the above-described embodiment, the main body **21** may also be made of a semiconductor material (resistant material) such as Si. In this case, it is not necessary to provide the resistance film **23** on the main body **21**, and the electron emission film **24** may also be formed directly on the main body **21** (formed at least on the inner wall surface **22***a*). Even in such a mode, an action and an effect similar to those of the above-described embodiment may be obtained. Since the manufacturing process of the resistance film **23** may be omitted, the manufacturing cost may be reduced.

INDUSTRIAL APPLICABILITY

According to one aspect of the present invention, it is possible to provide a microchannel plate and an electron multiplier capable of improving the gain while suppressing deterioration in gain over time.

REFERENCE SIGNS LIST

10 Microchannel plate
11 Substrate
11*a* Input surface (front surface)
11*b* Output side (rear surface)
12 Channel
12*a* Inner wall surface
13 Resistance film
14 Electron emission film (first film)
15 Protection film (second film)
16 Input electrode (electrode layer)
17 Output electrode (electrode layer)
20 Electron multiplier
21 Main body
21*a* One end face (front face)
21*b* Other end face (rear face)
22 Channel
22*a* Inner wall surface
23 Resistance film
24 Electron emission film (first film)
25 Protection film (second film)
26 Input electrode (electrode layer)
27 Output electrode (electrode layer)

The invention claimed is:

1. A microchannel plate comprising:
a substrate including a front surface, a rear surface, and a side surface;
a plurality of channels penetrating from the front surface to the rear surface of the substrate;
a first film provided on at least an inner wall surface of the channel;
a second film provided on at least a part of the first film; and
electrode layers provided on the front surface and the rear surface of the substrate,
wherein the first film is made of MgO,
the second film is made of SiO_2, and
the second film is thinner than the first film.

2. The microchannel plate according to claim **1**,
wherein the second film is distributed in an island shape on the first film.

3. The microchannel plate according to claim **1**,
wherein a thickness of the first film is 10 Å or more when being calculated by using X-ray fluorescence analysis.

4. The microchannel plate according to claim **1**,
wherein the substrate is made of an insulating material, and
a resistance film is formed between the inner wall surface of the channel and the first film.

5. The microchannel plate according to claim **1**,
wherein the substrate is made of a resistant material.

6. The microchannel plate according to claim **1**,
wherein the first film and the second film are formed on the front surface, the rear surface, and the side surface of the substrate, and
the electrode layers are formed on the second film.

7. The microchannel plate according to claim **1**,
wherein the electrode layers are formed so as to be in contact with the front surface and the rear surface of the substrate, and
the first film and the second film are formed on the electrode layers, and the front surface, the rear surface, and the side surface of the substrate.

8. The microchannel plate according to claim **4**,
wherein the resistance film, the first film, and the second film are formed on the front surface, the rear surface, and the side surface of the substrate, and
the electrode layers are formed on the second film.

9. The microchannel plate according to claim **4**,
wherein the electrode layers are formed so as to be in contact with the front surface and the rear surface of the substrate, and
the resistance film, the first film, and the second film are formed on the front surface, the rear surface, and the side surface of the substrate.

10. The microchannel plate according to claim **1**,
wherein the first film and the second film are layers formed by atomic layer deposition.

11. An electron multiplier comprising:
a main body including a front surface, a rear surface, and a side surface;
a channel penetrating from the front surface to the rear surface of the main body;
a first film provided on at least an inner wall surface of the channel;

a second film provided on at least a part of the first film; and

electrode layers provided on the front surface and the rear surface of the main body,

wherein the first film is made of MgO,

the second film is made of SiO_2, and

the second film is thinner than the first film.

12. The electron multiplier according to claim **11**,

wherein the second film is distributed in an island shape on the first film.

13. The electron multiplier according to claim **11**,

wherein a thickness of the first film is 10 Å or more when being calculated by using X-ray fluorescence analysis.

14. The electron multiplier according to claim **11**,

wherein the main body is made of an insulating material, and

a resistance film is formed between the inner wall surface of the channel and the first film.

15. The electron multiplier according to claim **11**,

wherein the main body is made of a resistant material.

16. The electron multiplier according to claim **11**,

wherein the first film and the second film are formed on the front surface, the rear surface, and the side surface of the main body, and

the electrode layers are formed on the second film.

17. The electron multiplier according to claim **11**,

wherein the electrode layers are formed so as to be in contact with the front surface and the rear surface of the main body, and

the first film and the second film are formed on the electrode layers, and the front surface, the rear surface, and the side surface of the main body.

18. The electron multiplier according to claim **14**,

wherein the resistance film, the first film, and the second film are formed on the front surface, the rear surface, and the side surface of the main body, and

the electrode layers are formed on the second film.

19. The electron multiplier according to claim **14**,

wherein the electrode layers are formed so as to be in contact with the front surface and the rear surface of the main body, and

the resistance film, the first film, and the second film are formed on the front surface, the rear surface, and the side surface of the main body.

20. The electron multiplier according to claim **11**,

wherein the first film and the second film are layers formed by atomic layer deposition.

21. The microchannel plate according to claim **4**,

wherein the resistance film is formed by laminating an Al_2O_3 layer and a Pt layer alternately.

22. The microchannel plate according to claim **4**,

wherein the first film is formed on an Al_2O_3 layer.

23. The microchannel plate according to claim **4**,

wherein the first film is formed on a Pt layer.

24. The electron multiplier according to claim **14**,

wherein the resistance film is formed by laminating an Al_2O_3 layer and a Pt layer alternately.

25. The electron multiplier according to claim **14**,

wherein the first film is formed on an Al_2O_3 layer.

26. The electron multiplier according to claim **14**,

wherein the first film is formed on a Pt layer.

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